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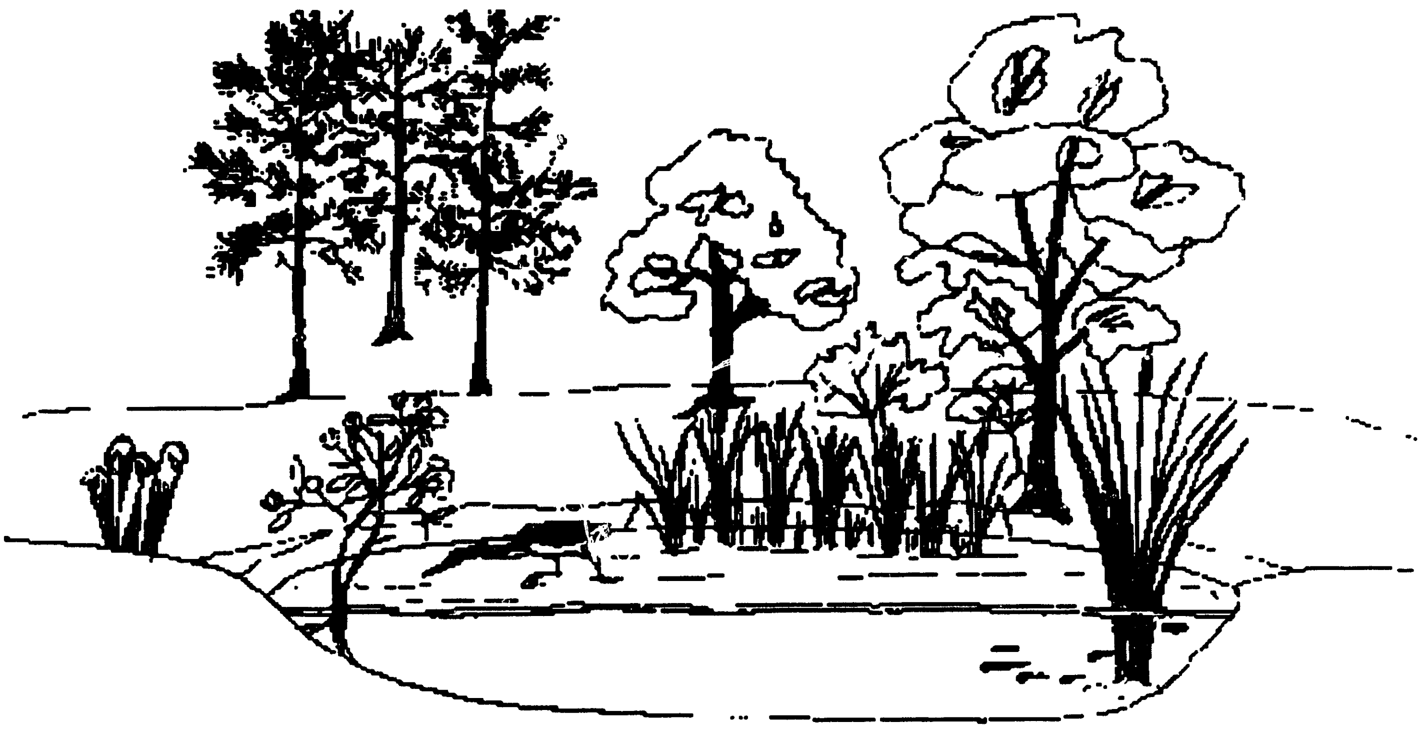
Ecological Studies Related to Construction of the Defense Waste Processing Facility on the Savannah River Site



Division of Stress and Wildlife Ecology
Savannah River Ecology Laboratory
University of Georgia

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December 1988

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ECOLOGICAL STUDIES RELATED TO THE CONSTRUCTION OF THE DEFENSE WASTE PROCESSING FACILITY ON THE SAVANNAH RIVER SITE

SREL--43

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FY-1987 AND FY-1988 Annual Report

Division of Stress and Wildlife Ecology

Savannah River Ecology Laboratory

University of Georgia

Drawer E

Aiken, SC 29802

December 1988

by

David E. Scott

Joseph H.K. Pechmann

John N. Knox

Ruth A. Estes

JoAnne H. McGregor

Research Manger and SREL Contact: William D. McCort

Editor: Kathy Bailey

Graphics: Jean B. Coleman

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FOREWORD

The Savannah River Ecology Laboratory (SREL) has completed ten years of ecological studies related to the construction of the Defense Waste Processing Facility (DWPF) on the Savannah River Site(SRS). Prior to construction, the 600-acre site (S-Area) contained a Carolina bay and the headwaters of a stream. Research conducted by the SREL has focused primarily on four questions related to these wetlands: 1) Prior to construction, what fauna and flora were present at the DWPF site and at similar, yet undisturbed, alternative sites? 2) By comparing the Carolina bay at the DWPF site (Sun Bay) with an undisturbed control Carolina bay (Rainbow Bay), what effect is construction having on the organisms that inhabited the DWPF site? 3) By comparing control streams with streams on the periphery of the DWPF site, what effect is construction having on the peripheral streams? 4) How effective have efforts been to lessen the impacts of construction, both with respect to erosion control measures and the construction of "refuge ponds" as alternative breeding sites for amphibians that formerly bred at Sun Bay?

Through the long-term census-taking of biota at the DWPF site and Rainbow Bay, SREL has begun to evaluate the impact of construction on the biota and the effectiveness of mitigation efforts. Similarly, the effects of erosion from the DWPF site on the water quality of S-Area peripheral streams are being assessed. This research provides the data necessary for compliance with the National Environmental Policy Act (NEPA) of 1969, the Endangered Species Act of 1973, Executive Orders 11988 (Floodplain Management) and 11990 (Protection of Wetlands), and United States Department of Energy (DOE) Guidelines for Compliance with Floodplain/Wetland Environmental Review Requirements (10 CFR 1022).

SUMMARY OF RESULTS AND MANAGEMENT IMPLICATIONS

A. Water quality monitoring of streams peripheral to the DWPF construction site

McQueen Branch is the principal drainage from the DWPF construction site and a tributary of Upper Three Runs (UTR) Creek. After rainfall, total suspended solids (TSS) levels in McQueen Branch were not significantly higher during FY-1987 and FY-1988 than in FY-1986. Turbidity reflected a similar pattern. The TSS pattern was most likely in response to variation in rainfall. Soil moving activities in S- and Z- areas appear to be less important for FY-1987 and 1988. Also, after rainfall TSS levels in McQueen Branch remained significantly higher than UTR Creek or Tinker Creek levels. TSS levels remained significantly higher in McQueen Branch for FY-1987 and 1988 than levels observed prior to construction.

For periods of no rainfall, TSS levels in McQueen Branch were significantly lower for FY-1987 and FY-1988 than in FY-1986. Turbidity showed a similar pattern. The TSS pattern appears to reflect a decrease in newly started construction activities in the drainage area. After periods of no rain, TSS levels in McQueen Branch were not significantly different in FY-1987 and 1988 than levels observed prior to construction.

Stream profile and flow measurements were initiated at McQueen Branch and Tinker Creek during FY-1986 in order to calculate TSS loading (expressed in kilograms of TSS per day per square kilometer of drainage). After rainfall, the two sites on McQueen Branch were significantly higher than Tinker Creek (unimpacted site). The loading pattern followed the pattern of rainfall. For periods of no rain, the two McQueen Branch sites were not significantly higher than Tinker Creek.

The FY-1983-84 Annual Report concluded that, during periods of heavy rainfall, inputs from McQueen Branch were sufficient to increase the TSS load of UTR Creek below the confluence with McQueen Branch. FY-1986 data supported this statement in two instances. For FY-1987 and FY-1988 McQueen Branch TSS inputs continued to increase TSS in UTR Creek, but Tinker Creek inputs also appeared to be contributing at times during both years. This pattern also held for turbidity and percent ash weight. Because this pattern was also present prior to construction, it is difficult to assess the impact on UTR Creek of these individual rainfall events and DWPF construction.

After rainfall, TSS levels in UTR Creek were not significantly different in FY-1987 and FY-1988 from the portion of UTR Creek unimpacted by the construction compared to the portion of UTR Creek below the construction. For periods of no rainfall, the same patterns of no significant differences were seen for the two portions of the Creek.

TSS and turbidity data were compared with the United States Environmental Protection Agency (USEPA) expired proposed criteria. After rainfall, TSS values exceeded the Federal levels mainly for McQueen Branch and Crouch Branch. The same pattern was true of the turbidity data. FY-1983 (i.e., pre-construction) TSS data were used to establish a background for comparison; the percentage of TSS data from McQueen Branch which exceeded the Federal level was calculated. The data from FY-1985, FY-1986, FY-1987 and FY-1988 exceeded this "background" level. For periods of no rain, TSS and turbidity values exceeded the Federal levels only in McQueen and Crouch branches. The TSS data for FY-1984 and FY-1986 exceeded the pre-construction percentages for McQueen Branch.

It can be assumed that higher TSS levels would be observed in McQueen Branch if erosion control measures (i.e., settling basins, grass seeding, and hay bales) had not been implemented. However, this cannot be accurately assessed since there are no data for a construction-impacted stream during the same time period without control measures.

Three recommendations were made.

1. Sampling for the particle size composition of McQueen Branch should be terminated, due to lack of relation to the TSS loadings seen in this creek. The data should be retained for possible comparison after construction is completed.

2. Consideration should be given to finding ways to increase the efficiency of the three sedimentation basins on McQueen Branch and Crouch Branch.
3. Two trends should continue to be examined.

   a. decreasing TSS and turbidity in McQueen Branch and Crouch Branch, not associated with rain events, and
   b. increasing turbidity in UTR Creek below the construction site after rain events.

B. Amphibian studies related to DWPF construction

Amphibians comprised more than 95% of the total non-avian vertebrate fauna at the DWPF site prior to construction. By FY-1988, captures of amphibians at the former Sun Bay site had dwindled to near zero. At the Rainbow Bay control site, amphibian breeding population sizes were relatively low due to drought conditions in FY-1988, but most species were in no danger of local extinction. Compared to the unimpacted Rainbow Bay control site, the Sun Bay amphibian community was impacted heavily by DWPF construction.

Results of the refuge pond experiment in mitigation indicated that refuge ponds (i.e., alternative breeding sites) may have ameliorated construction impacts on many, but not all, species. In general, frogs and toads colonized the refuge ponds sooner than did salamanders. In FY-1987 and FY-1988, two species of salamanders and eight species of frogs and toads bred successfully in the refuge ponds, and produced juveniles that emigrated from the ponds.

Environmental variation has a strong influence on the population dynamics of amphibian species. For example, variation in the amount of time that Rainbow Bay holds water (i.e., its hydroperiod) has affected the reproductive success of three ambystomatid salamander species. Each species may have certain "optimum" conditions under which it performs best. The effects of occasional good years for a species are stored in the population and enable it to persist through sub-optimal or catastrophic years. This sort of hydroperiod variation is non-existent at the refuge ponds, which are nearly permanent ponds that never dry, and may partially explain the reduced species composition of amphibians at the refuge ponds.

I. INTRODUCTION AND OVERVIEW

David E. Scott and Joseph H.K. Pechmann

Ecological studies related to the construction of the DWPF on the SRS were begun by SREL in FY-1979. Two areas have been used for biological surveys and long-term monitoring: the DWPF construction site (S-Area), and two control sites (Rainbow Bay and Tinker Creek). The Rainbow Bay study area and S-Area are located within 5 km of each other on the SRS (Fig I-1), and both once contained Carolina bays which were very similar ecologically (SREL 1980). One goal of the SREL's faunal studies is to compare the natural variation in amphibian populations at the Rainbow Bay control site to the variation observed at the human-altered site (Sun Bay, formerly on the DWPF construction site). Amphibian populations exhibit large year-to-year variation in population size and breeding success (Vitt 1981, Vitt et al. 1982), thus long-term studies are necessary to separate natural variation from variation due to human perturbations.

Pre-construction biological surveys included data on vegetation, birds, mammals, amphibians, reptiles, fish, and several invertebrate groups (SREL 1979, 1980). No species on the Federal Endangered or Threatened lists were found on either site, but several plants and animals of threatened or special-concern status in South Carolina were present (SREL 1980, Vitt 1981).

DWPF construction began in FY-1984. Continuing studies are directed towards assessing its impacts on the biota. Primary emphasis is being placed on evaluating the effectiveness of mitigation measures undertaken by the DOE.

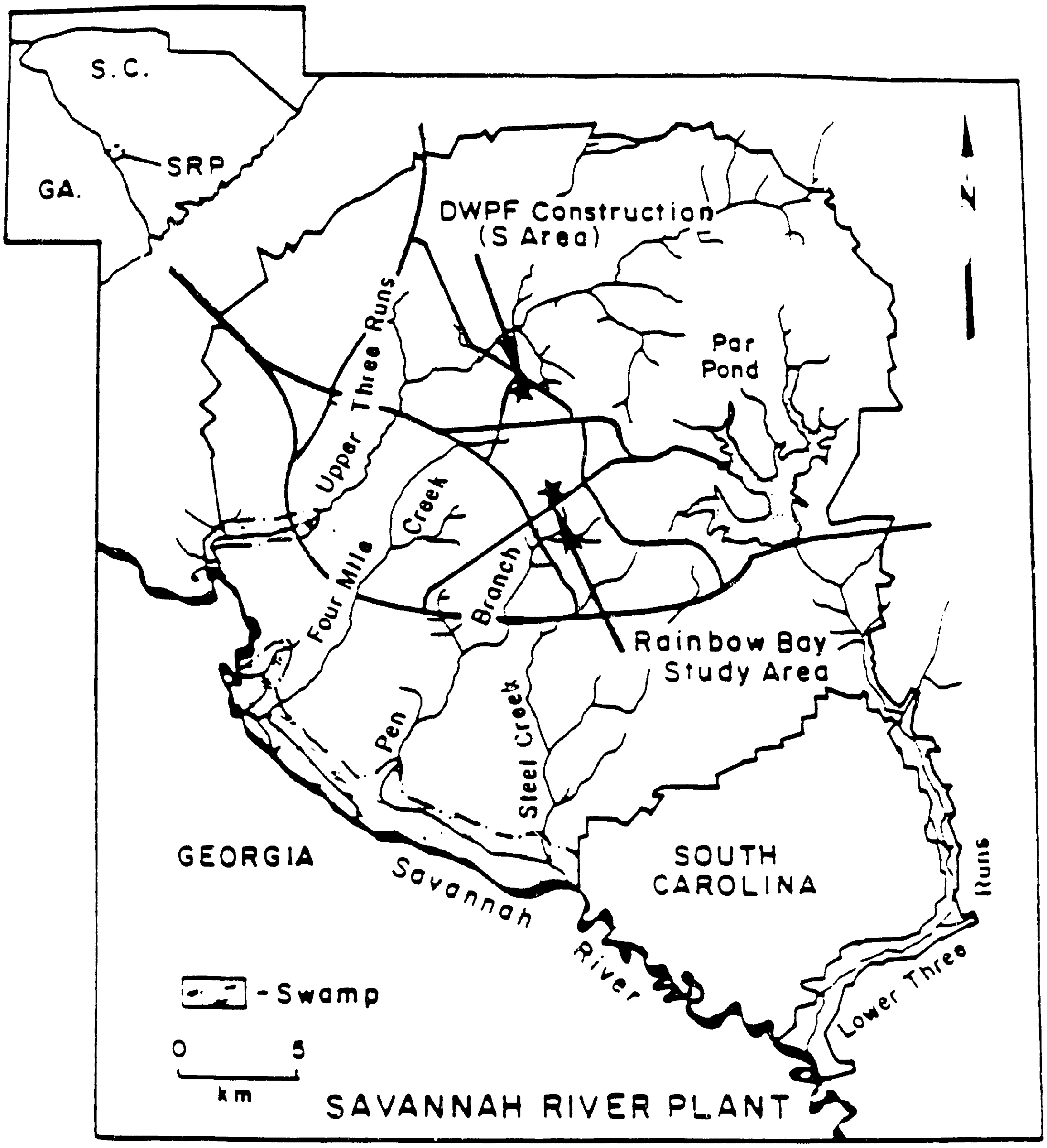

Figure I-1 Locations of the DWPF construction site (S-Area) and the Rainbow Bay Study Area (control site) on the Savannah River Site.

SREL began baseline water quality monitoring on S-Area peripheral streams in November 1982 (prior to construction) to quantify natural variation in water quality parameters. Sampling has continued to the present on the streams that drain the DWPF site (Upper Three Runs Creek, McQueen Branch, and Crouch Branch, Figure II-1) and on a nearby, unimpacted blackwater stream, Tinker Creek. Erosion resulting from DWPF construction potentially could affect the productivity and biotic diversity of McQueen Branch, Crouch Branch, and Upper Three Runs Creek. Results of a baseline survey of macroinvertebrates in these streams were reported in Pechmann et al. (1984). Chapter II of this report contains the FY-1987 and FY-1988 water quality results, and an assessment of the effectiveness of erosion control measures which have been implemented during the DWPF construction (U.S. DOE 1982).

In FY-1984, the DWPF construction eliminated Sun Bay in S-Area. Carolina bays are extremely productive, natural wetlands (Sharitz and Gibbons 1982) which serve as important breeding sites for many species of amphibians (Bennett et al. 1979, Gibbons and Semlitsch 1982, Sharitz and Gibbons 1982). Amphibians are the most prevalent group of vertebrates on both the Rainbow Bay control site and the DWPF site (SREL 1980). A major objective of the SREL studies has been to evaluate the effects of the loss of Sun Bay on the breeding success of amphibians in S-Area (Pechmann et al. 1985). In an experimental attempt to mitigate the loss of the natural breeding habitat in S-Area (i.e., Sun Bay), four refuge ponds were constructed. Only three of these are currently in operation, because of the loss of one due to unanticipated construction activities. The effectiveness of the refuge ponds as alternative breeding sites is discussed in Chapter III.

The long-term nature of the Rainbow Bay study (currently ten years) has allowed the natural variation in numbers of immigrating breeding adults and of emigrating juveniles at the control site to be documented, and compared with data from Sun Bay and S-Area. Hydroperiod, or the number of days a site holds water during a year, is a critical determinant of amphibian breeding success and persistence. Chapter IV addresses differences in reproductive modes and population dynamics among the ambystomatid salamander species, and discuss how these differences may be related to environmental (i.e., hydroperiod) variability.

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II. WATER QUALITY MONITORING OF PERIPHERAL STREAMS

John N. Knox

INTRODUCTION

The Savannah River Ecology Laboratory monitoring program, designed to assess the potential impact of the DWPF construction activities on peripheral stream quality, began in November 1982. Upper Three Runs (UTR) Creek, which drains this area, is the only major stream on the Savannah River Plant that has not been impacted significantly by thermal discharge.

The first 11 months of monitoring provided baseline information on the natural water quality characteristics of UTR Creek and two of its relevant tributaries. Rough grading of the construction site began on September 15, 1983 (Pechmann et al. 1984) and data subsequent to this date have been used to evaluate construction impacts and the effectiveness of erosion control measures. Erosion mitigation is particularly important due to the biologically detrimental consequences of increased siltation and turbidity. Because stream siltation was anticipated in the Environmental Impact Statement (US DOE, 1982), the major emphasis of the SREL assessment program has been the identification of significant increases in total suspended solids (TSS) in UTR Creek.

METHOD

Site Selection

The SREL monitoring program in the past has focused on ten sites in the UTR watershed. Currently, nine sites are used (Fig. II-1). Three primary sites (3, 4a, and 4b) were located on McQueen Branch, the principle drainage from the construction area. Currently, two sites (3 and 4) are located on McQueen Branch. Site 3 is located

DWPF WATER QUALITY MONITORING SITES

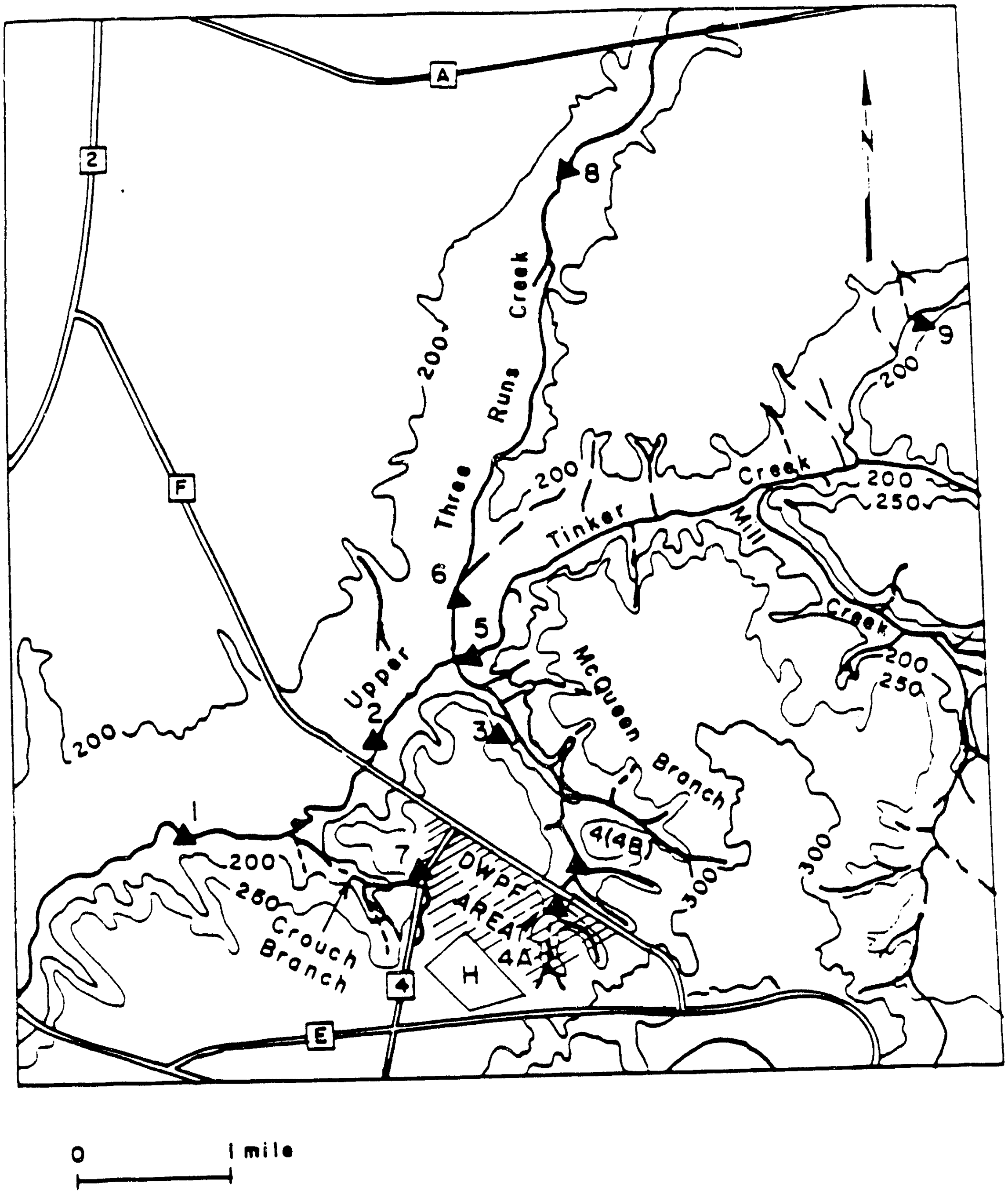

Figure II-1. DWPF Water Quality monitoring sites.

approximately 2 km downstream of the construction area. Site 4b was formerly site 4 which was located adjacent to the construction area on the northern side of Road F. In November 1984, site 4 was relabeled site 4b, and site 4a was added on McQueen Branch, south of Road F. This change was made to determine whether runoff from a highway ditch on the north side of Road F was impacting the former site 4. In October 1986, site 4b was deleted and site 4a relabeled site 4 (south of Road F). This change was made after a review of data for FY-1983 to FY-1986 showed no significant difference for any of the parameters sampled at 4a and 4b.

Another site (site 7) is located on Crouch Branch at Road 4 approximately 122 m (400') downstream on the outfall of Sedimentation Basin 1. Site 7 was reactivated during FY-1986, having been sampled twice in 1982 before sampling ceased because of low water levels.

Two sites (sites 1 and 2) are located on UTR Creek below the confluence with McQueen Branch, and two more sites (sites 6 and 8) are located on UTR Creek above this confluence. Near this confluence with McQueen branch, UTR Creek is also joined by another tributary (Tinker Creek) that is comparable in size to UTR Creek but has the potential for different water quality characteristics. Two sites on Tinker Creek (sites 5 and 9) are monitored to evaluate whether potential water quality changes in UTR Creek below McQueen Branch also reflected inputs from Tinker Creek. Sites 5 and 6 are located immediately above the junction of Tinker Creek and UTR Creek while sites 8 and 9 are located approximately 8 km upstream from the confluence.

Sampling and Analytical Methods

During the second to sixth year of sampling (November 1983 to September 1988), water quality monitoring was conducted monthly. During the first year (November 1982 to October 1983), sampling was conducted more frequently and with greater emphasis on sampling during and after rainfall for the purpose of establishing existing water quality characteristics.

SREL personnel measured the following water quality variables: specific conductance, turbidity (minimal sampling during the first year), total suspended solids (TSS), and ash weight of the suspended solids. Until February 1985, specific conductance was measured with a field conductivity bridge. Samples since February 1985 were analyzed in the laboratory using a Sybron PM-70CB conductivity bridge or an Orion Research Conductivity Meter Model 101 (25°C). Turbidity was determined in the laboratory using a nephelometer which measured for total suspended solids and ash weight using EPA approved methods (US EPA, 1983). A rain gauge was placed adjacent to the DWPF construction site and monitored daily.

Stream profiles and flow measures were added to the routine sampling in October 1985 at three sites: 4 (McQueen Branch), 3 (McQueen Branch), and 9 (Tinker Creek). Site 4 is the furthest upstream site on McQueen Branch (the principle drainage from the construction site), site 3 is approximately 2 km downstream from 4, and site 9 on Tinker Creek was used as a control site for comparisons. Stream velocities (centimeters per second) were measured using a Marsh-McBirney Portable Flow Meter.

The data summarized in this report cover six fiscal years. The first year, Fiscal year 1983 (FY-1983), included data taken prior to the start of construction at the DWPF site. Sampling did not begin until November 1982; therefore, there are eleven months of data for FY-1983. The second through sixth years, FY-1984 to FY-

1988, include data taken during construction; there is data for all 12 months of each of these years.

Although there were data collected for Crouch Branch during FY-1985, they were preliminary and constitute in a small data set (4 observations/parameter). These observations are included in each of the figures summarizing the data but were not used in any yearly comparisons or statistical analyses due to the small sample size.

At the beginning of FY-1986, four plots were established on McQueen Branch to inventory the particle size composition and to observe composition changes over time. The plots are each 7.6 m (25 ft) long and were marked with yellow stakes at each corner. Locations are as follows: M01-M04, approximately 120 m upstream of site 4; M05-M08, approximately 6 m upstream of site 4; M09-M12, approximately 6 m downstream of site 4; and M13-M16, approximately 4 m upstream of site 3. At each sampling plot, six sediment cores were taken, evenly spaced across the length and width of the plot in a diagonal line. Coring depths varied but were made as deep as possible with a hand corer. After air drying, the sediments were separated using six Standard Testing Sieves (Numbers 5, 18, 35, 60, 120 and 230). The preliminary sampling (January 31, 1986) was analyzed using both dry and wet sieve procedure, and no difference was found in the percent silt/clay portion; therefore, the dry sieve method was used for the actual analysis. The particle size ranges and names (Wentworth grade classification) were taken from a marine benthos handbook (Holme and McIntyre 1971) and are described in Table II-1.

Table II-1. Wentworth grade classification used to describe McQueen Branch sediments.

Name	Grade Limits
Pebble	64-4 mm
Granule	4-2 mm
Very coarse sand	2-1 mm
Coarse sand	1-0.5 mm
Medium sand	500-250 µm
Fine sand	250-125 µm
Very fine sand	125-62 µm
Silt/clay	below 62 µm

From: Holme, N. A. and A. D. McIntyre, editors. 1971.

Data Analyses

Data were analyzed using SAS version 5.16 statistical package (SAS Institute Inc. 1985a and 1985b). The General Linear Model (GLM) procedure was used to compare different time periods and locations. Data that were not normally distributed and had large differences in the variances were transformed. The transformation was made by adding 1.0 to each observation then taking the natural log of that sum. These transformations resulted in more nearly normally distributed data and smaller differences in the variances. Data transformed were: total suspended solids (TSS), turbidity, specific conductance, and TSS load per day per square kilometer. A level of significance (α) equal to 0.05 was chosen for testing differences. Data were grouped into six watershed locations: the two McQueen Branch sites (3 and 4), the two Tinker Creek sites (5 and 9), the two UTR Creek sites above McQueen Branch (6 and 8), the one UTR Creek site below McQueen Branch (2), the one UTR Creek site below Crouch Branch (1) and the Crouch Branch site (7).

The data were partitioned into two other groups based upon rainfall. One group consisted of data for which rainfall occurred one day before sampling, and the other group was data for which no rainfall occurred one day before sampling. This grouping was based upon a comparison of TSS vs. total rainfall relationships during different time intervals: the amount of rainfall one day before sampling, two days before sampling, three days before sampling, and two weeks before sampling. Rainfall one day before sampling had the most significant correlation ($r = 0.50437$; $p = 0.0001$) with the log transformed TSS. Because TSS is of most interest in this study, all other data were reviewed using these same two groups.

Most results are presented graphically; group means are plotted, and the overall (grand) variation of the data (one standard deviation) is stated in the figure legend for each parameter. Appendices A and B list numeric summaries of the data by Fiscal Year and by rainfall group. Measured values and log transformed values are given in these Appendices along with standard error values. Numeric summaries are given in the text for McQueen Branch sediment levels and Federal water quality criteria comparisons.

The following abbreviations are used on the water quality figures: "UTR Ck Above" for the two UTR Creek sites (6 and 8) above McQueen Branch, "UTR Ck Below" for the UTR Creek site (1) below both Crouch Branch and McQueen Branch; "Crouch Br" for the site (7) on Crouch Branch; "McQueen Br" for the two sites (3 and 4) on McQueen Branch; "Tinker Ck" for the two sites (5 and 9) on Tinker Creek; "UTR Ck Mid." for the site (2) on UTR Creek directly below McQueen Branch but above Crouch Branch; "Lower McQueen" for site 3 on McQueen Branch; "Tinker Ck--Site 9" for site 9 on Tinker Creek; and "Upper McQueen" for site 4 on McQueen Branch.

For this report, less emphasis is placed upon Crouch Branch than in previous reports. Crouch Branch is discussed in terms of general trends and patterns and how these relate to McQueen Branch. This approach was taken to place more emphasis upon UTR Creek and examine trends for UTR Creek.

RESULTS

McQueen Branch

Rainfall one day before sampling

For the period of record (FY-1983 to FY-1988), total suspended solids (TSS), turbidity, percent ash weight (percent ash) and specific conductance (conductance) were significantly higher (all $p < 0.0001$) in McQueen Branch than all other locations except Crouch Branch (see Figures II-2, II-3, II-4 and II-5). Preconstruction (FY-1983) data is lacking for turbidity. McQueen Branch displayed different patterns of change for TSS and turbidity relative to the other locations for FY-1983 to 1985 (see Figures II-2 and II-3) but displayed similar patterns for FY-1986-88. These TSS and turbidity patterns roughly match rainfall patterns for FY-1986-88 (Figure II-6). The patterns for percent ash and conductance were not as clear as for TSS and turbidity.

Values for FY-1986 were compared to FY-1987 and FY-1988 for McQueen Branch. None of the parameters (TSS, turbidity, percent ash and conductance) were significantly different between those years.

McQueen Branch pre-construction (FY-1983) values were compared to FY-1987 and FY-1988. In the latter years TSS, percent ash and conductance were all significantly higher ($p < 0.001$, $p < 0.001$, and $p < 0.05$, respectively) than before construction.

TSS loading rates have been measured at three sites (two on McQueen Branch, one on Tinker Creek) for three years, FY-1986 to FY-1988. There is no comparable data for the pre-construction year (FY-1983). The drainage area above the uppermost site on McQueen Branch (site 4) is approximately 3 km^2. The second downstream on McQueen Branch (site 3) has an approximate 10 km^2 drainage area; and the drainage above the Tinker Creek site (site 9) is about 70 km^2. Overall, for the three years, the McQueen Branch upper site has been significantly higher ($p = 0.0033$) than the background site (Tinker Creek, see Figure II-7). Also, the combined McQueen Branch sites were significantly higher ($p = 0.0167$) than Tinker Creek. There is no overall significant difference between the two McQueen Branch sites.

<u>No rainfall one day before sampling</u>

For the period of record, TSS levels, turbidity, percent ash, and conductance were significantly higher ($p \leqq 0.0001$,for all comparisons) in McQueen Branch than other locations except Crouch Branch (see Figures II-8, II-9, II-10 and II-11). McQueen Branch displayed a different pattern of change relative to other locations. TSS and turbidity showed a marked decrease over the past three years (Figures II-8 and II-9). Percent ash showed a slight decrease for the same period (Figure II-10).

Values for FY-1986 were compared to FY-1987 and FY-1988 for McQueen Branch. Only TSS and turbidity levels were significantly lower than FY-1986 (for TSS, $p < 0.05$ in FY 1987, $p < 0.001$ in FY1988; for turbidity, $p < 0.01$ in FY 1987 and $p < 0.01$ in FY1988).

McQueen Branch pre-construction values were compared to FY-1987 and FY-1988. A small number of turbidity observations were made in FY-1983 but were not used for a year-to-year comparison. There were no significant differences in TSS levels. Percent ash levels were significantly higher in FY-1987 and 1988 than in the pre-construction period ($p<0.001$ for both tests). FY-1988 was significantly higher ($p < 0.001$) than FY-1983 for conductance.

Overall, for the three years, TSS loading rates were not significantly different between McQueen Branch and Tinker Creek (background site). Also the combined McQueen Branch sites were not significantly different than Tinker Creek. There was a decrease in FY-1988 for the two McQueen Branch sites (Figure II-12). There is no significant difference between the two McQueen Branch sites.

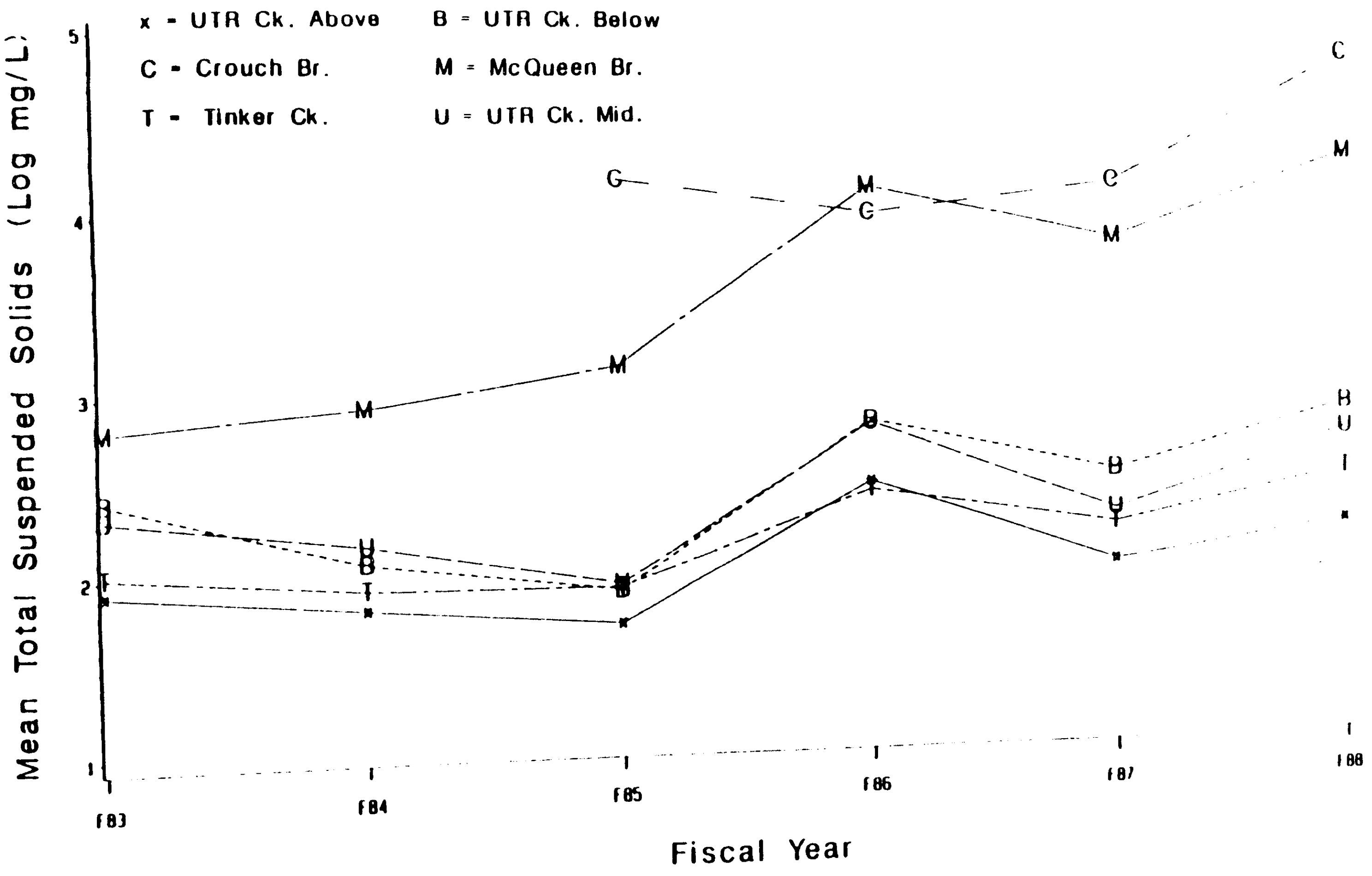

Figure II-2. Mean log total suspended solids by Fiscal Year. Includes only dates when rainfall occurred one day before sampling. Overall variation = ±0.8, one standard deviation. Sample sizes vary from 1 to 24.

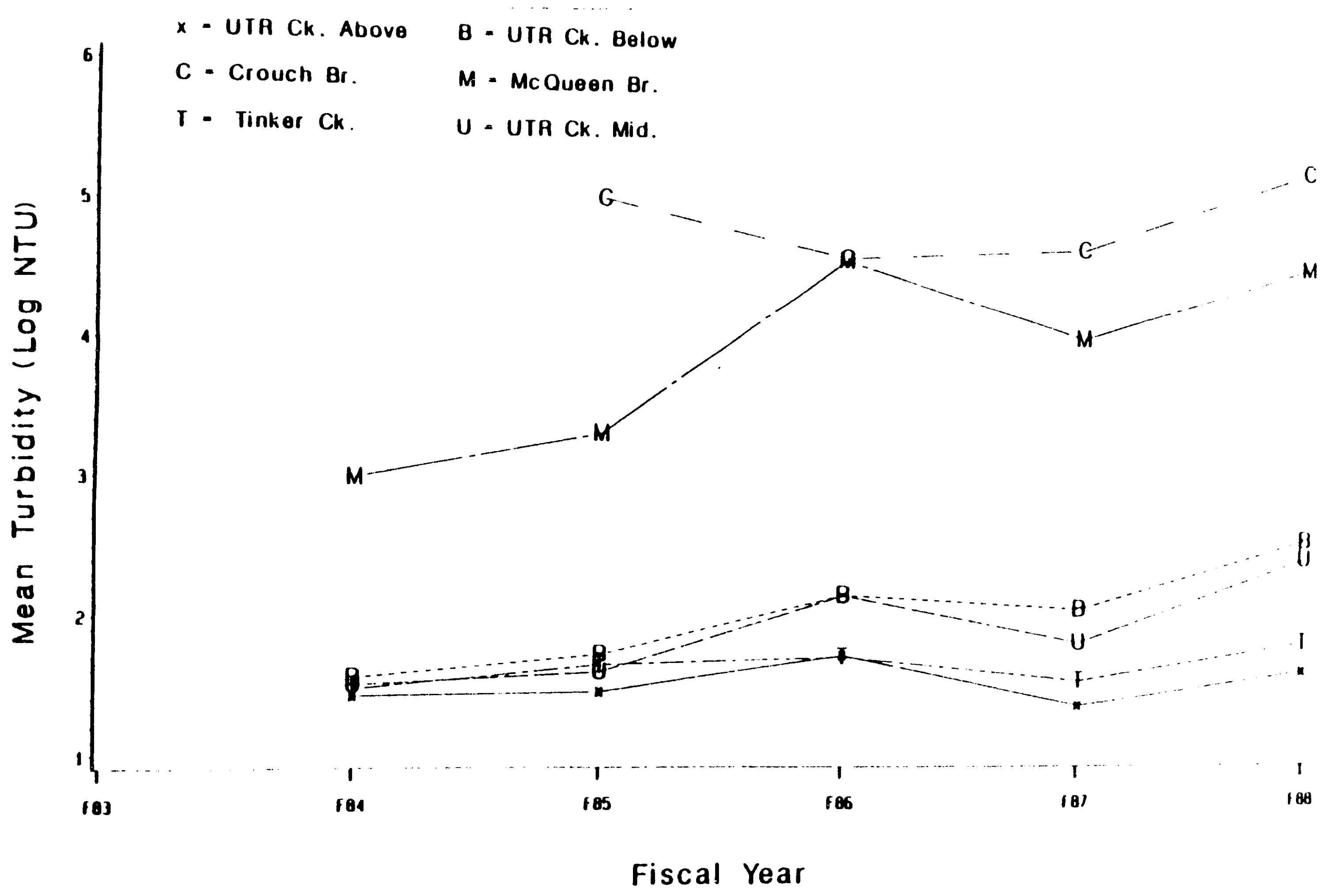

Figure II-3. Mean log turbidity by Fiscal Year. Includes only dates when rainfall occurred one day before sampling. Overall variation = ± 1.0, one standard deviation. Sample sizes vary from 1 to 20.

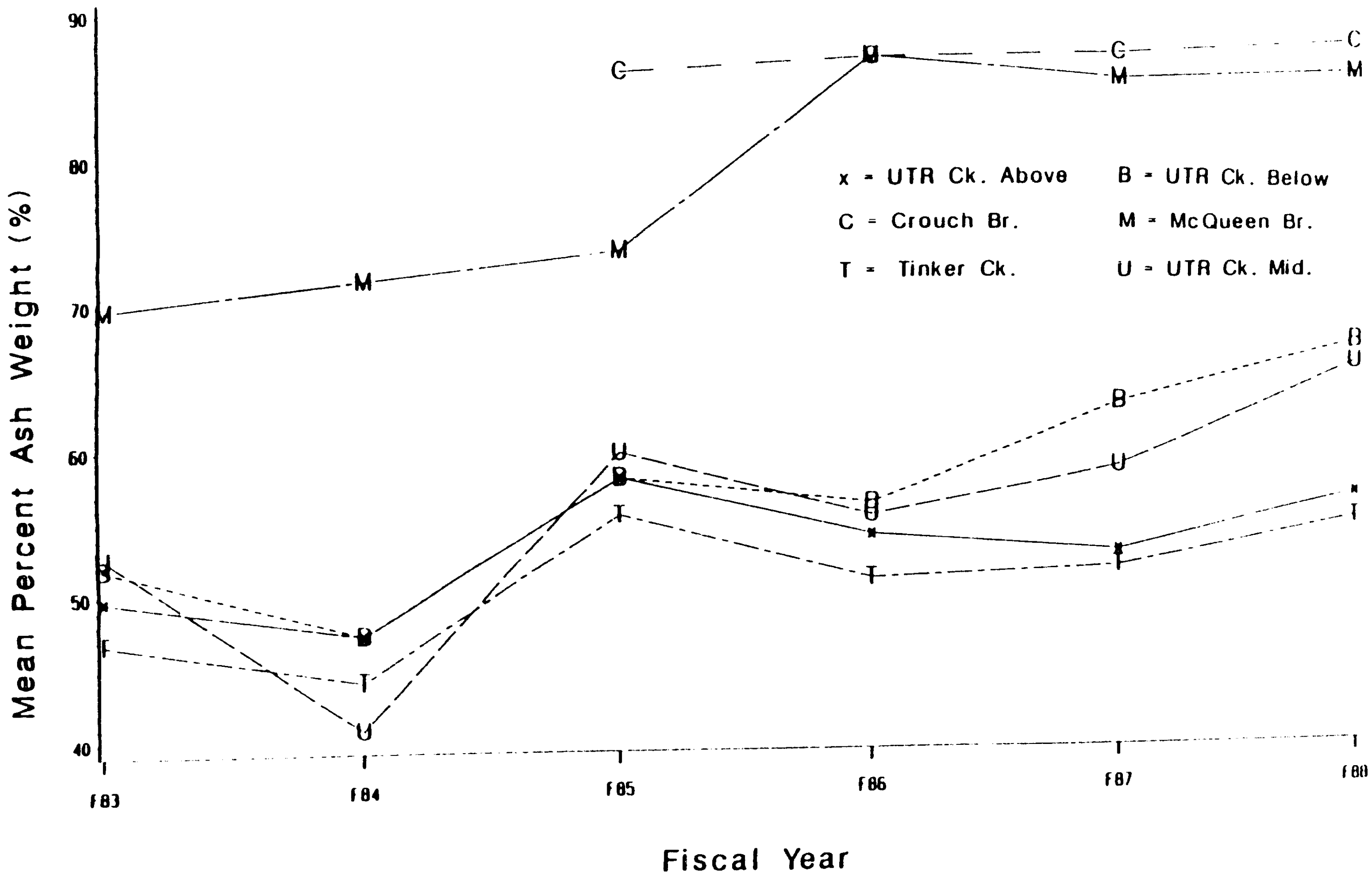

Figure II-4. Mean percent ash weight by Fiscal Year. Includes only dates when rainfall occurred one day before sampling. Overall variation = ± 8.5, one standard deviation. Sample sizes vary from 1 to 22.

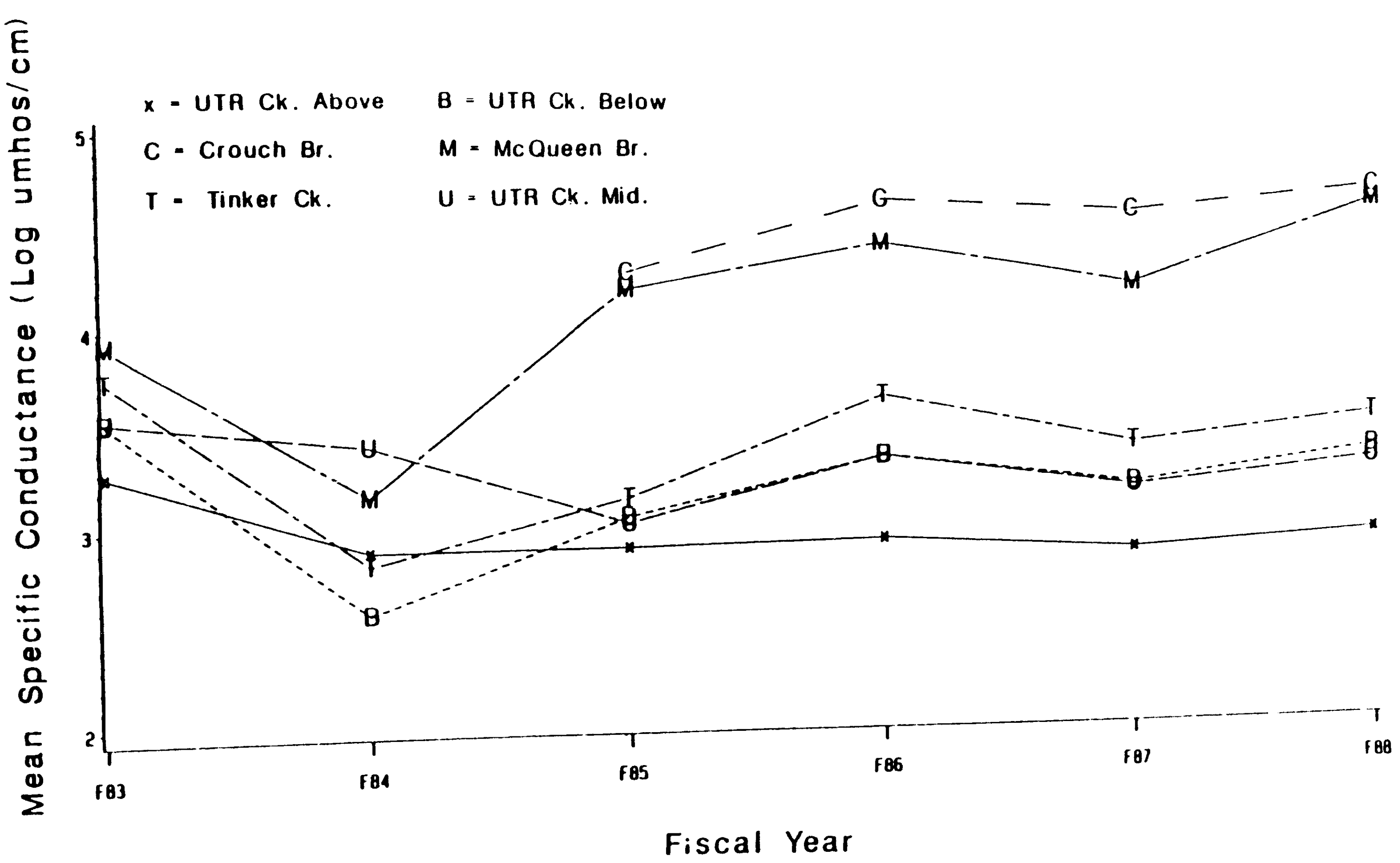

Figure II-5. Mean log specific conductance by Fiscal Year. Includes only dates when rainfall occurred one day before sampling. Overall variation = ±0.4, one standard deviation. Sample sizes vary from 1 to 20.

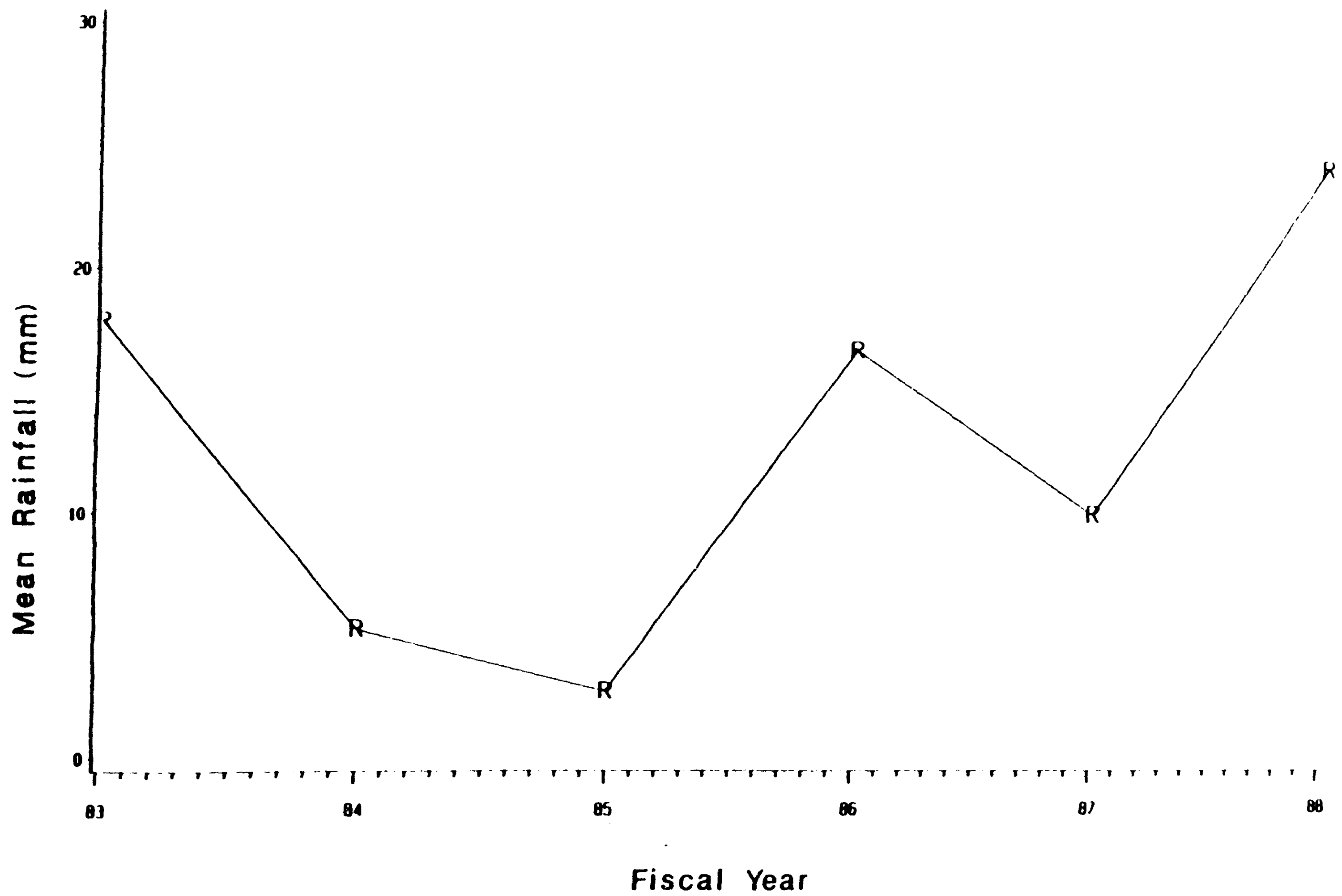

Figure II-6. Mean rainfall one day before sampling for sample dates in Fiscal Years 1983 through 1988.

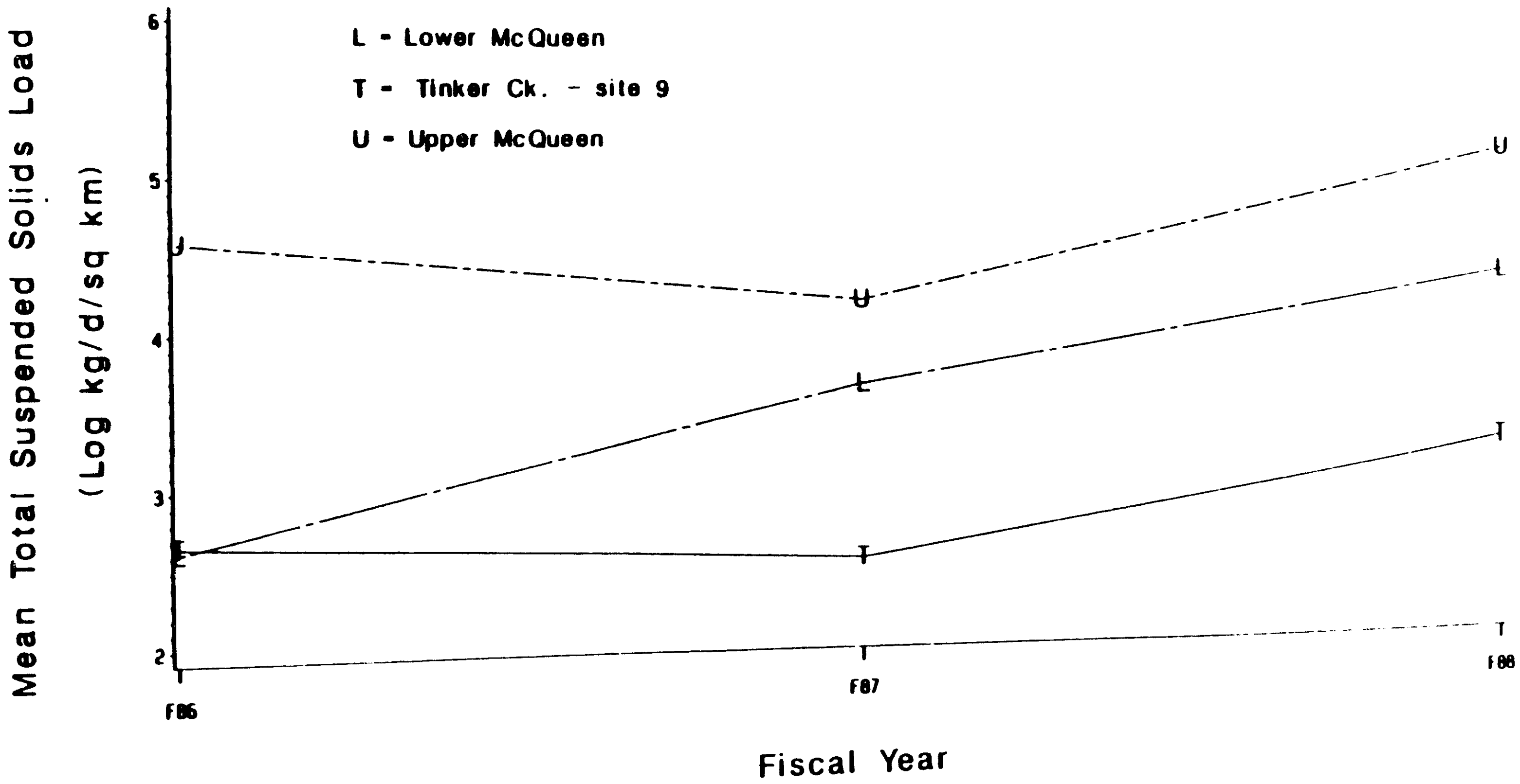

Figure II-7. Mean log total suspended solids load by Fiscal Year. Includes only dates when no rainfall occurred one day before sampling. Overall variation = ± 1.7, one standard deviation. Sample sizes vary from 3 to 10.

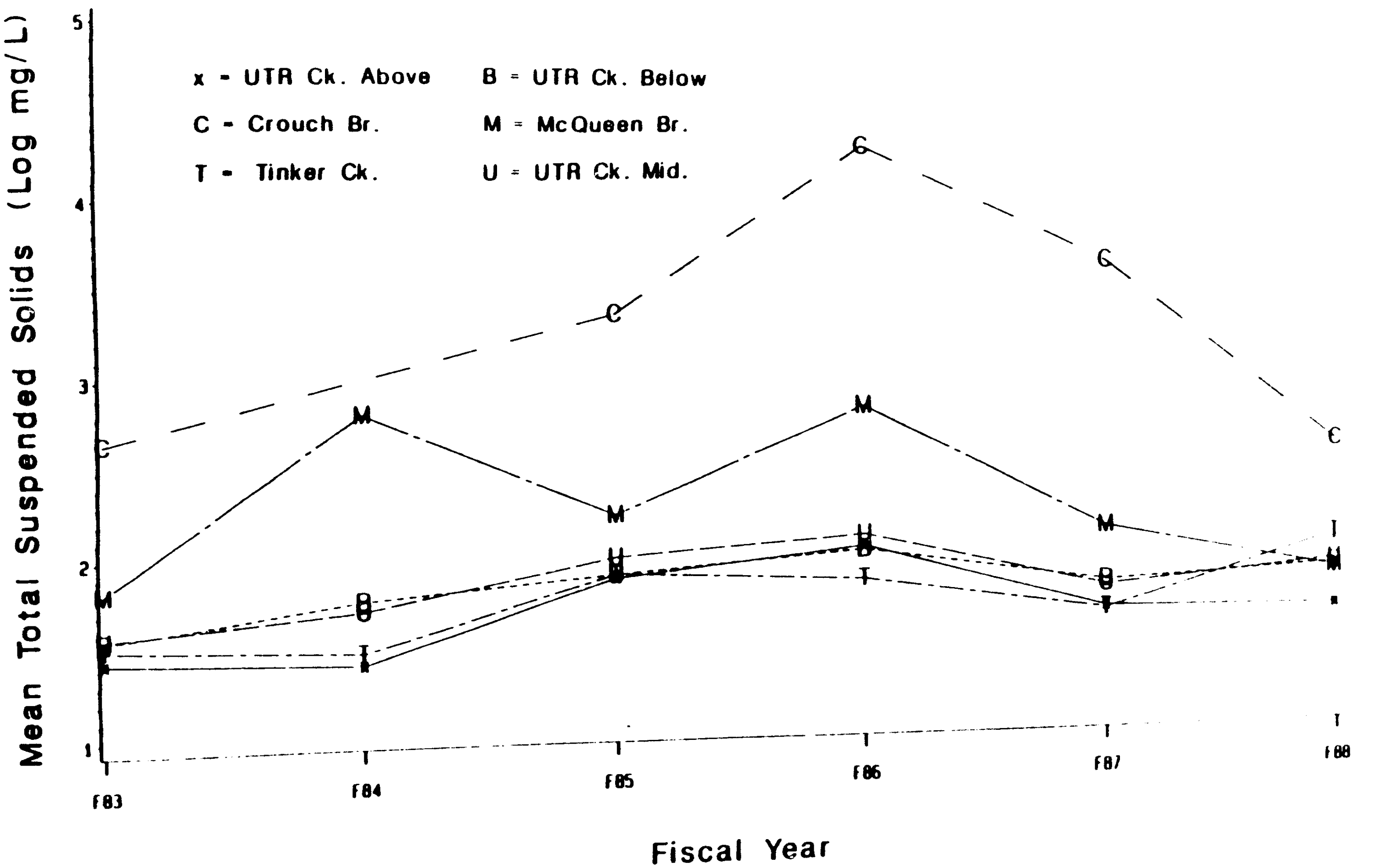

Figure II-8. Mean log total suspended solids by Fiscal Year. Includes only dates when no rainfall occurred one day before sampling. Overall variation = ±0.6, one standard deviation. Sample sizes vary from 1 to 29.

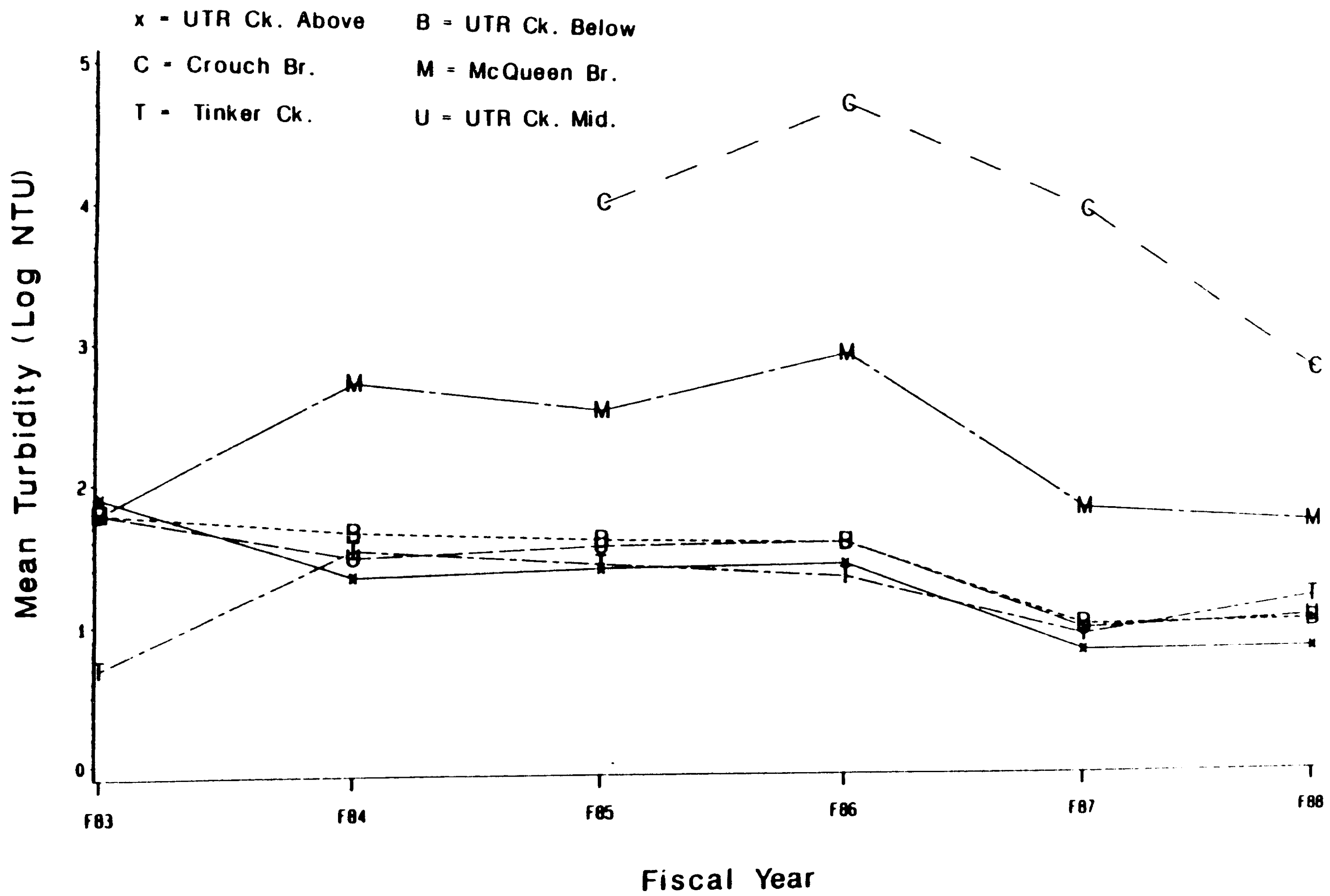

Figure II-9. Mean log turbidity by Fiscal Year. Includes only dates when no rainfall occurred one day before sampling. Overall variation = ±0.7, one standard deviation. Sample sizes vary from 1 to 29.

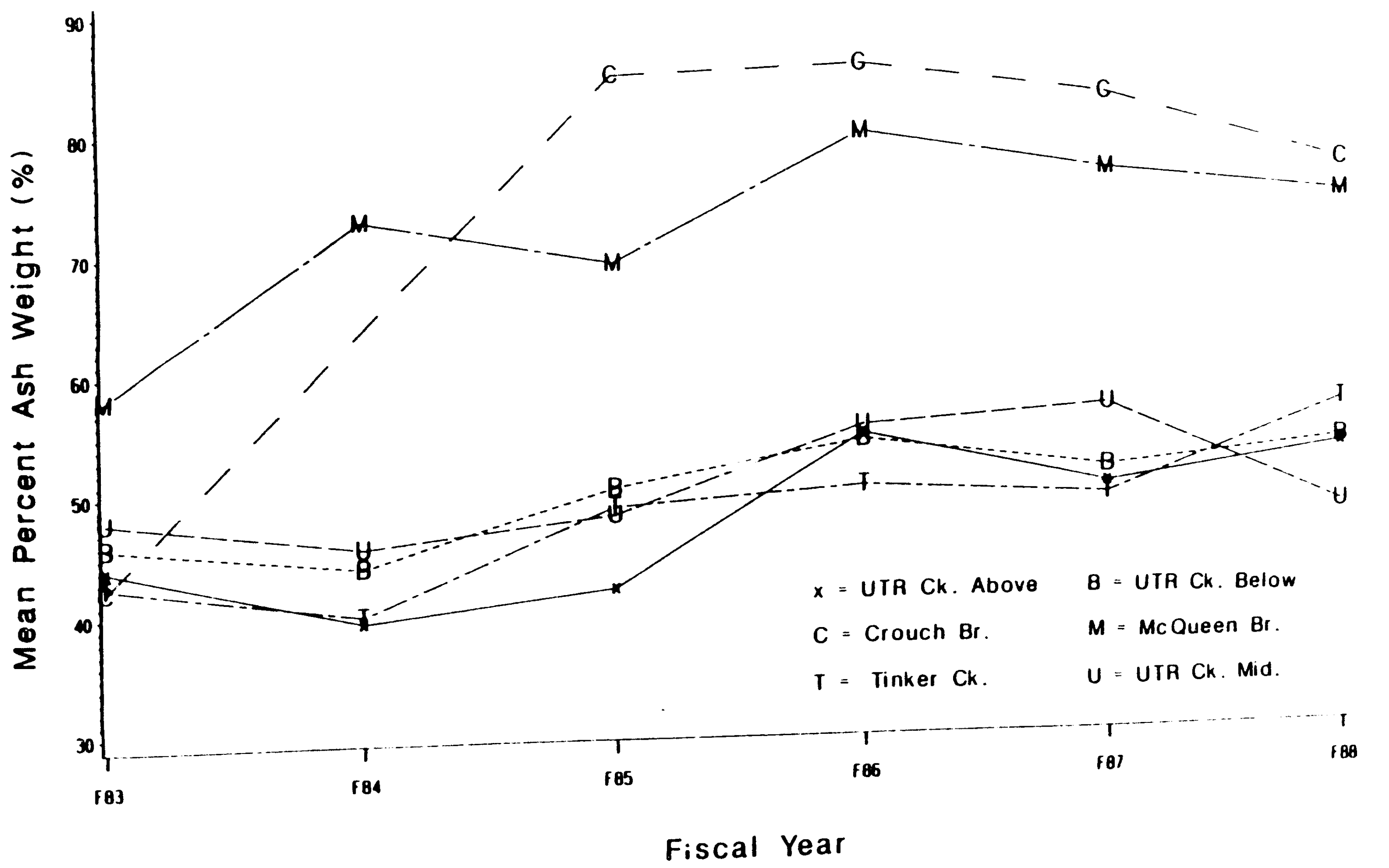

Figure II-10. Mean percent ash weight by Fiscal Year. Includes only dates when no rainfall occurred one day before sampling. Overall variation = ±7.9, one standard deviation. Sample sizes vary from 1 to 29.

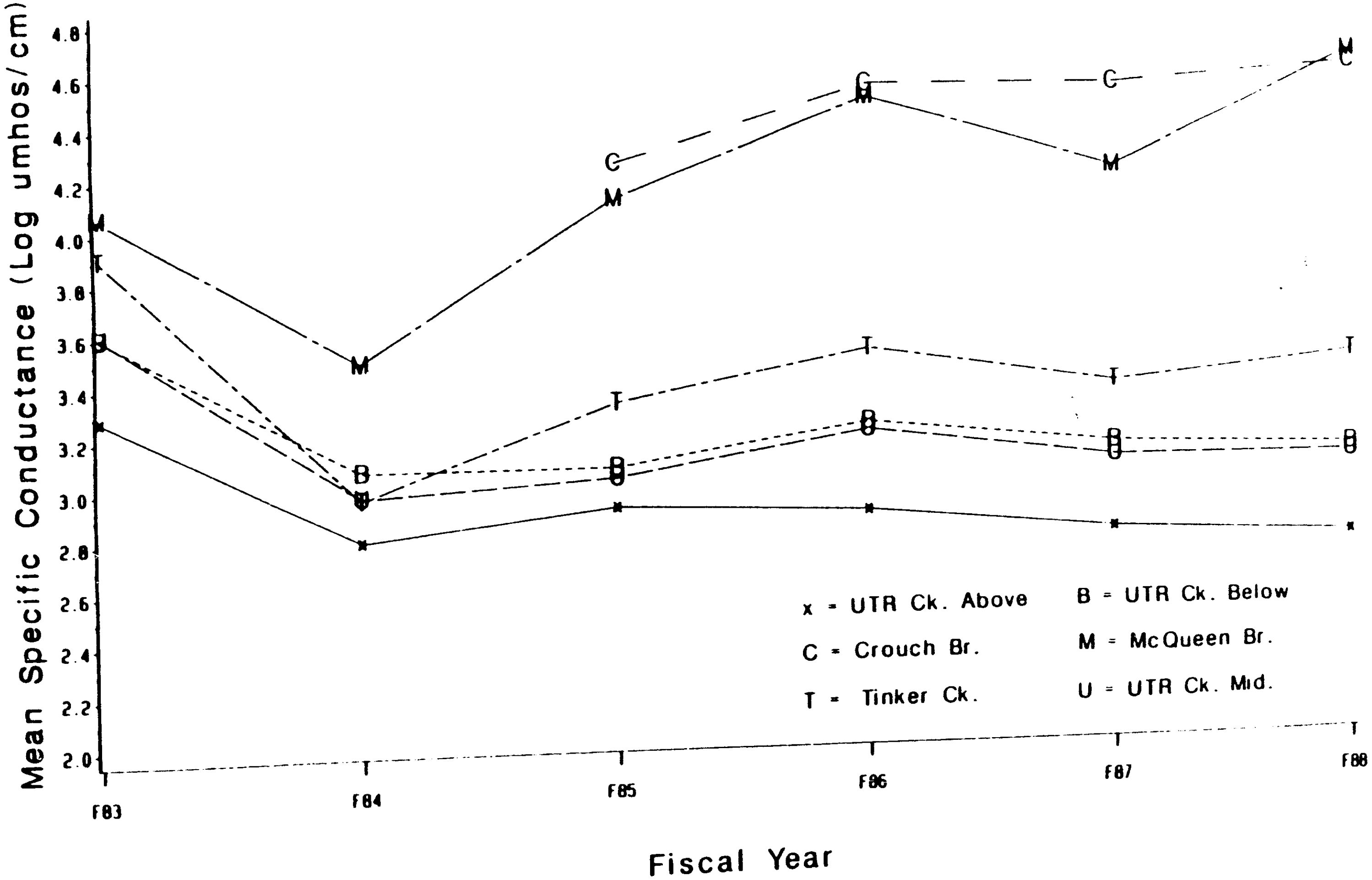

Figure II-11. Mean log specific conductance by Fiscal Year. Includes only dates when no rainfall occurred one day before sampling. Overall variation = ± 0.3, one standard deviation. Sample sizes vary from 2 to 22.

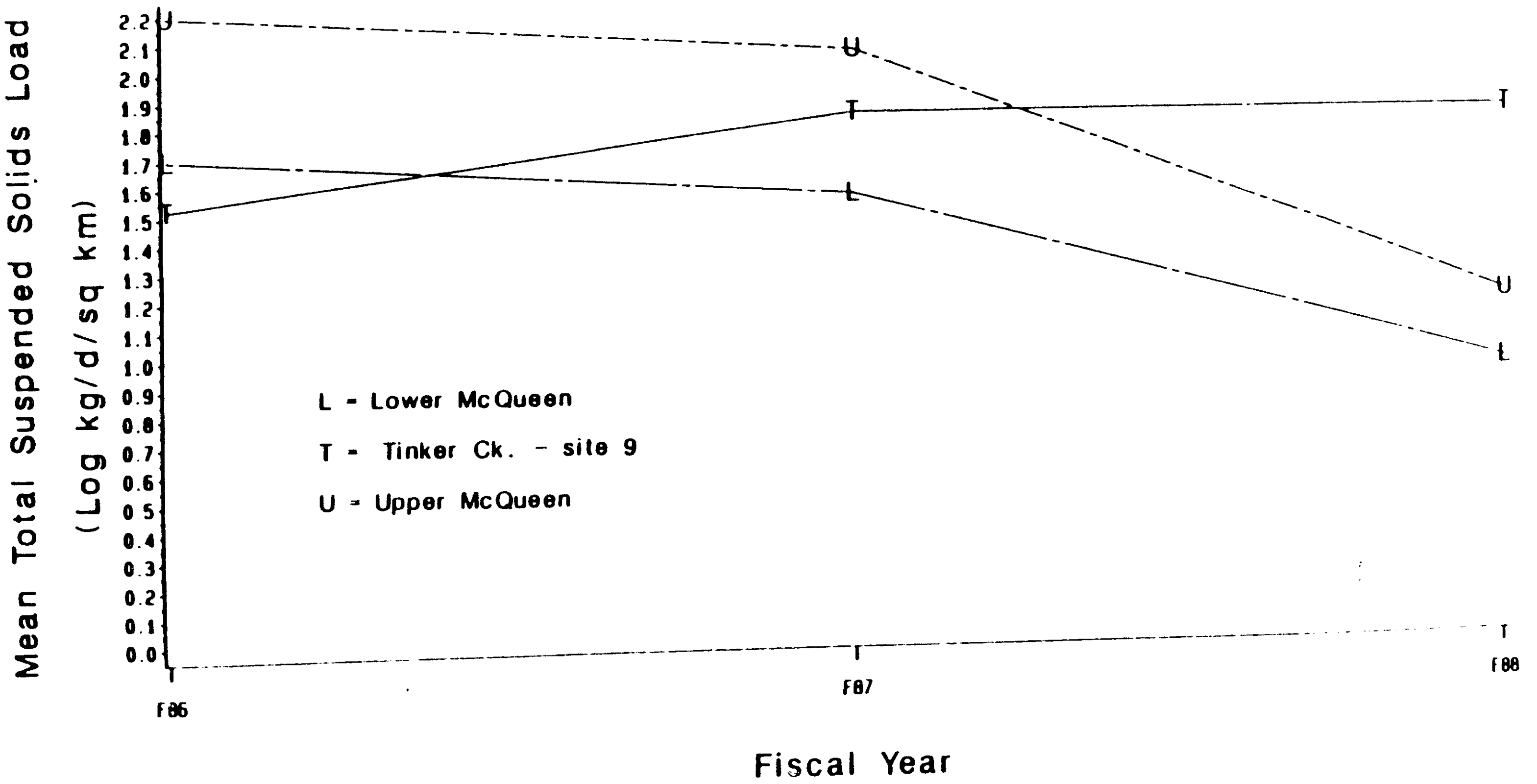

Figure II-12. Mean log total suspended solids load by Fiscal Year. Includes only dates when no rainfall occurred one day before sampling. Overall variation = ±0.8, one standard deviation. Sample sizes vary from 2 to 9.

Crouch Branch--Trends

Rainfall one day before sampling

For available data (FY-1985 to 1988), TSS and turbidity levels in Crouch Branched increased, similar to the changes that occurred in McQueen Branch (see Figures II-2 and II-3). No change was observed for the same time period for percent ash or conductance levels in Crouch Branch.

No rainfall one day before sampling

TSS and turbidity levels in Crouch Branch dropped drastically from FY-1986 to FY-1988, similar to the decreases observed in McQueen Branch, . A slight decrease was observed in Crouch Branch percent ash levels, and a slight increase was observed in conductance levels.

Upper Three Runs Creek

Rainfall one day before sampling

For the period of record, TSS levels, percent ash weight (percent ash), and specific conductance (conductance) were significantly higher ($p = 0.0334$, $p = 0.0330$, and $p = 0.0144$) in the portion of UTR Creek below (UTR--Below) the DWPF construction than in UTR Creek above (UTR--Above) the construction runoff (see Figures II-2, II-4 and II-5). Turbidity levels were not significantly different (Figure II-3).

For FY-1983 (pre-construction), there were no significant differences between UTR--Above and UTR--Below for TSS, percent ash or conductance. No turbidity data were taken.

For FY-1987, there were no significant differences between UTR--Above and UTR--Below for TSS or turbidity. Percent ash and conductance were significantly higher ($P < .01$) at UTR--Below than UTR--Above, but conductance levels were below pre-construction levels (see Figure II-5).

For FY-1988, there was no significant difference between UTR--Above and UTR--Below for TSS. Turbidity, percent ash, and conductance were significantly higher in UTR--Below than UTR--Above, but again conductance levels were below pre-construction levels (Figure II-5).

No rainfall one day before sampling

For the period of record, only conductance levels were significantly higher ($p = 0.0002$) in UTR--Below than UTR--Above (see Figures II-8, II-9, II-10 and II-11). For FY-1983, again only conductance levels were significantly higher ($p < .01$) in UTR--Below than UTR--Above. For FY-1987 and FY-1988 none of the parameters showed any significant differences between UTR--Below and UTR--Above.

DISCUSSION

McQueen/Crouch Branches

Rainfall one day before sampling

As reported in the 1986 Annual Report (Scott et al. 1986), increases in TSS levels at McQueen Branch during FY-1986 were similar to but more dramatic than at other locations. Two factors were given in the 1986 Report as probable causes: an increase in rainfall and an increase in soil-moving or soil-disturbing activities. Activities started during the third construction year (FY-1986) included seven excavation sites at S-Area, five excavation sites at Z-Area, grading and soil stock-piling at Z-Area and railroad embankments through S-Area to Z-Area (Wolf, Kathleen Z. [Memo] 1986). The large exposed areas of soil, particularly on the railroad embankment, may have acted as funnels and concentrated surface runoff in certain locations.

Activities started during FY-1987 included two excavation sites at S-Area and six excavation sites at Z-Area (Wolf, Kathleen Z. [Memo.a.] 1988). All these were localized excavations, not wide-scale disturbances such as the railroad embankments in FY-1986. Three activities were begun in FY-1988, all in Z-Area (Wolf, Kathleen Z. [Memo.b.] 1988), and all were localized, two involving excavation.

The TSS and turbidity patterns seen for FY-1987 and FY-1988 for McQueen and Crouch Branches (Figures II-2 and II-3) and TSS loading for McQueen (Figure II-7) cannot be explained solely by construction activity in their drainage areas. Construction activity appears to have declined for FY-1987 as did the TSS and turbidity levels for McQueen Branch. Construction activity appears to have continued to decline for FY-1988, but not the TSS or turbidity levels in McQueen. Response to rainfall (Figure II-6) appears to better explain the variations in McQueen Branch, but Crouch Branch does not reflect the rainfall changes as closely. Decreased erosion control efficiency is probably also a factor, but no direct data exist to support this. It can be assumed that over FY-1987 and FY-1988 as the three storm run-off sedimentation basins continues to trap sediment, their efficiency has declined.

For the McQueen Branch drainage in FY-1987 and FY-1988, rainfall was likely the driving force underlying variation in the TSS and turbidity, with new construction activity having a lesser role in this drainage area. For Crouch Branch, rainfall was partly responsible for the TSS and turbidity variation, but the combined factors of construction and erosion control efficiency probably had a greater role in this drainage area.

Of the three factors discussed (rainfall, construction, and sedimentation basins) the most manageable factor is the set of three sedimentation basins. Consideration should be given to finding ways to increase the efficiency of these basins.

No rainfall one day before sampling

This is the first Annual Report to partition the data into rain events and non-rain events, and a different pattern emerged after splitting the data. Using only the non-rain data, the TSS and turbidity levels in McQueen and Crouch Branches (Figure II-8 and II-9) declined in FY-1988 to approximately FY-1983 levels (pre-construction). The TSS load in McQueen Branch also shows a similar pattern for three years available (Figure II-12). These trends during FY-1987 and FY-1988 indicate a decrease during dry periods in the impacts associated with construction activities. The fall-off in newly started construction activities discussed above was probably a factor. It appears that during times not associated with a rain event, TSS and turbidity levels returned to levels approximating pre-construction levels. Levels will continue to be monitored to see if they remain low.

UTR Creek

Rainfall one day before sampling

Variation in TSS and turbidity levels (Figure II-2 and II-3) in UTR Creek follow the rainfall pattern for the last three years. But the TSS patterns seen in Figure II-2 show no overall effects of McQueen or Crouch Branch; no differences were observed between the unimpacted area of UTR Creek (UTR--Above) and the impacted area (UTR--Below). However, one-time discharge events from McQueen and Crouch, after heavy rainfall, have been seen to elevate UTR TSS levels (see section on individual rainfall events). There appears to be a trend developing for turbidity levels in UTR Creek (Figure II-3), as UTR--Below was significantly higher than UTR--

Above. This trend in turbidity should be watched for differences which may grow stronger.

No rainfall one day before sampling

UTR Creek shows no similar decreasing trends over time in TSS or turbidity levels, as discussed for McQueen and Crouch Branches. This result reinforces the idea that construction-related changes in the drainage areas of Crouch and McQueen Branches contributed to changes in water quality within each branch.

Individual Rainfall Events

The FY-1983-84 Annual Report (Pechmann et al. 1984) concluded that there were indications that, during periods of heavy rainfall, inputs from McQueen Branch were sufficient to effect an increase in the TSS loading of UTR Creek below the confluence with McQueen, compared to UTR Creek above the confluence. FY-1986 data supported this statement; although there were no significant increases for TSS, turbidity or percent ash weight using year-mean comparisons, there were two instances of increases of TSS, turbidity, and percent ash weight after heavy rainfalls in UTR Creek below the confluence of McQueen Branch (Scott et al. 1986).

In FY-1987 and FY-1988, inputs from McQueen Branch and Crouch Branch during periods of heavy rainfall continued to increase the TSS loading in UTR Creek. During FY-1987,TSS in UTR Creek was increased due to contributions from McQueen and Tinker Creek in March, May and August (Table II-2). Once (December) the increase could be attributed to McQueen Branch alone. During FY-1987, Crouch Branch contributed to TSS increases in UTR Creek after heavy rainfall on four occasions: December, March, May and August. In FY-1988, TSS levels in UTR Creek increased due to combined contributions from McQueen Branch and Tinker Creek four times (March, April, June, and September). On one date (November) the increase in UTR Creek was due to inputs from McQueen Branch alone. During March and June (FY-1988) Crouch Branch also contributed to TSS increases in UTR Creek.

McQueen Branch Sediment

Table II-3 summarizes the sediment composition of McQueen branch for FY-1986 and FY-1987.

From Table II-3 for FY-1986 coarse sand and medium sand were the predominant portions of the sediments, 23.4% to 31.3% and 18.7% to 30.4%, respectively. The mean percent composition of pebbles in the sediments had a wide range from 4.4% to 23.2%. Silt and clay comprised a small portion of the sediment (0.2% to 0.4%).

For FY-1987 coarse and medium sand were also the predominant portions of the sediments, 19.1% to 28.9% and 24.9% to 49.8%, respectively. The mean percent composition of pebbles ranged from 0.6% to 14.5%. Silt and clay comprised a small portion from 0.0% (none detected) to 0.2%.

In the FY-1986 Annual Report, among-plot comparisons were made using two nonparametric tests, the Wilcoxon rank-sum test and Spearman's rank-order correlation. There was a decrease detected in silt/clay content from upstream to downstream with plot M01-M04 (furthest upstream) being significantly higher ($p = 0.0006$) than M13-M16 (furthest downstream) (Scott et al., 1986). This was not expected. With the decrease in TSS loading seen from the load and flow data, an increase in small particle accumulation was expected. The percent of very fine sand and medium sand did show an increase from upstream to downstream, with M13-M16 being significantly larger ($p = 0.0011$ and 0.0008) than M01-M04 (Scott et al. 1986).

Table II-2 One day rainfall (mm) preceding the sampling date for each Fiscal Year.

	FY-1983[1]	FY-1984	FY-1985	FY-1986	FY-1987	FY-1988
Oct.	--	0.0	0.0	0.0	0.4	0.0
Nov.	0.4	0.0	0.2	0.0	1.6	17.7
Dec.	4.6	0.0	0.0	0.0	15.2	1.8
Jan.	0.0	0.2	0.0	0.0	0.2	8.0
Feb.	81.9	0.0	6.8	0.0	0.0	2.5
Mar.	23.7	0.0	0.0	0.0	13.8	27.0
Apr.	0.2	0.0	0.0	8.4	2.7	28.0
May	16.5	0.0	0.0	19.3	18.2	0.0
June	0.0	3.4	0.0	0.0	8.2	80.6
July	4.0	12.4	1.4	24.0	3.0	0.0
Aug.	2.8	0.0	0.0	0.0	40.6	6.6
Sept.	80.2	0.0	0.0	0.0	0.0	57.4
Totals	214.3	16.0	8.4	51.7	103.9	229.6

[1]*Largest rainfall sampled during a month with multiple samplings.*

Table II-3. Summary statistics for particle size composition of McQueen Branch sediment by percent (%) at four sample plots. Values presented are the mean (x), standard error (s.e.), minimum (Min.), and maximum (Max.) for each group; N = 8 for all groups.

	% at M01-M04 x ± s.e (min-max)	% at M05-M08 x ± s.e (min-max)	% at M09-M12 x ± s.e (min-max)	% at M13-M16 x ± s.e (min-max)
FY-1986 (Aug. 19, '86)				
Pebbles	21.4 ± 2.4(9.3-28.2)	15.3 ± 2.8(5.4-28.0)	23.2 ± 5.0(7.2-47.6)	4.4 ± 0.5(2.4-6.4)
Granules	10.3 ± 0.6(7.2-11.5)	11.1 ± 0.6(8.4-13.3)	8.5 ± 0.4(7.2-10.1)	8.0 ± 0.3(6.7-8.8)
Very Coarse sand	19.7 ± 0.7(15.6-22.2)	19.5 ± 0.8(16.6-24.0)	11.9 ± 0.6(9.4-13.9)	17.9 ± 0.4(15.6-19.5)
Coarse sand	23.4 ± 0.8(21.0-27.7)	23.8 ± 1.1(19.9-29.1)	18.3 ± 1.1(12.8-21.5)	31.3 ± 0.3(30.1-32.7)
Medium sand	18.7 ± 1.0(15.2-22.7)	22.1 ± 1.2(16.2-27.8)	26.7 ± 2.2(16.3-34.5)	30.4 ± 0.5(28.2-31.9)
Fine sand	4.9 ± 0.4(3.4-7.0)	6.5 ± 0.6(4.6-10.4)	9.3 ± 1.2(5.0-15.2)	6.2 ± 0.1(5.7-7.0)
Very Fine sand	0.9 ± 0.1(0.6-1.3)	1.3 ± 0.2(0.9-2.3)	1.7 ± 0.3(0.8-3.5)	1.5 ± 0.1(1.3-1.7)
Silt/Clay	0.4 ± 0.0(0.3-0.5)	0.3 ± 0.0(0.3-0.4)	0.3 ± 0.0(0.2-0.5)	0.2 ± 0.0(0.2-0.3)
FY-1987 (June 9, '87)				
Pebbles	1.7 ± 0.4(0.1-3.2)	14.5 ± 5.2(0.6-46.5)	14.0 ± 2.2(4.9-22.5)	0.6 ± 0.2(0.2-1.8)
Granules	3.5 ± 0.3(2.7-5.2)	8.0 ± 0.3(6.7-8.9)	10.4 ± 0.4(8.5-11.7)	2.4 ± 0.1(2.1-2.7)
Very Coarse sand	12.6 ± 0.9(8.8-17.0)	14.9 ± 0.6(11.8-17.2)	14.1 ± 0.4(12.8-16.2)	8.5 ± 0.2(7.8-9.1)
Coarse sand	28.9 ± 0.5(26.1-30.6)	24.6 ± 1.7(15.9-30.2)	19.1 ± 0.5(17.6-22.1)	28.5 ± 0.4(26.9-30.0)
Medium sand	42.9 ± 1.4(36.7-49.7)	30.0 ± 2.3(15.8-35.2)	24.9 ± 1.1(20.9-29.9)	49.8 ± 0.3(48.2-51.5)
Fine sand	8.9 ± 0.5(6.9-11.1)	6.8 ± 0.7(2.7-8.5)	13.9 ± 1.0(11.1-18.3)	9.3 ± 0.2(8.0-10.1)
Very Fine sand	1.2 ± 0.1(1.0-1.6)	1.0 ± 0.1(0.3-1.5)	3.1 ± 0.3(2.2-4.2)	0.8 ± 0.0(0.6-1.0)
Silt/Clay	0.2 ± 0.0(0.2-0.2)	0.2 ± 0.0(0.0-0.3)	0.6 ± 0.0(0.5-0.9)	0.0 ± 0.0(0.0-0.1)

Using a GLM factorial interaction model, the FY-1986 silt/clay content was significantly different from plot to plot. No decrease in content downstream for FY-1986 was detected. For FY-1987 there were no significant differences for silt/clay content from plot to plot.

Comparing FY-1986 to FY-1987 values (overall, not plot by plot), there were no significant differences in silt/clay or very fine sand percent ages. These two sediment categories were used as they are most likely to be linked to the suspended sediment load.

WATER QUALITY CRITERIA

The levels used to compare TSS and turbidity data are both expired proposed Federal criteria. The upper limit for turbidity (50.0 JTU) was recommended in 1968 (National Technical Advisory Committee, 1968) and the upper limit for TSS (80.0 $mg \cdot L^{-1}$) was recommended in 1973 (USEPA, 1973). Currently, there are no Federal numeric criteria for either TSS or turbidity. These expired proposed levels were used as a literature-based comparison to discuss variation in TSS and turbidity among streams over time.

Rainfall one day before sampling

TSS levels exceeded the Federal 80-$mg \cdot L^{-1}$ value mainly in McQueen Branch (14.3% to 61.1% of the samples) and Crouch Branch (33.3% to 77.8%) (Table II-4). One observation at UTR Creek--Below exceeded 80.0 $mg \cdot L^{-1}$ in FY-1983, but may be due to pre-construction site preparation. If FY-1983 is used as a "background" year for TSS level in McQueen Branch (14.3% of the data exceeded 80.0 $mg \cdot L^{-1}$), then all subsequent increased years have been higher than background. The percent of the samples from McQueen Branch that exceeded 80.0 $mg \cdot L^{-1}$ increased from FY-1985 to FY-1988. Insufficient data are available for Crouch Branch to make a pre-

Table II-4. Summary of data exceeding expired proposed Federal criteria for periods of rainfall one day before sampling for FY-1983 to FY-1988. Percent of data exceeding (%), minimum value exceeding the standards or criteria (min.), maximum value exceeding the standards or criteria (max.) and number of observations exceeding the standards or criteria (N).

	TSS (80 mg·L-1) **% (min-max) N**	**Turbidity (50 JTU)** **% (min-max) N**
UTR--Above		
FY83-FY88	0.0 -- -- --	0.0 -- -- --
Tinker		
FY83-FY88	0.0 -- -- --	0.0 -- -- --
McQueen		
FY83	14.3(81.6-114.9)2	0.0 -- -- --
FY84	0.0(-- --)--	16.7(62)1
FY85	16.7(152.1)1	16.7(252)1
FY86	33.3(125.9-143.2)2	83.3(67-260)5
FY87	36.8(95.1-655.0)7	52.6(82-650)10
FY88	61.6(80.2-331.2)11	66.7(93-495)12
UTR--Middle		
FY83-FY88	0.0 -- -- --	0.0 -- -- --
FY88	0.0 -- -- --	22.2(58-74)2
Crouch		
FY83	0.0 -- -- --	Not Sampled
FY84	Not Sampled	Not Sampled
FY85	0.0 -- -- --	100.0(158)1
FY86	33.3(93.8)1	66.7(110-210)2
FY87	55.6(80.7-215.5)5	77.8(93-390)7
FY88	77.8(135.4-398.3)7	88.9(130-670)8
UTR--Below		
FY83	8.3(105.7)1	0.0 -- -- --
FY84-87	0.0 -- -- --	0.0 -- -- --
FY88	0.0 -- -- --	33.3(58-78.5)3

construction comparison, but since FY-1986 percents of dates on which the 80.0 - $mg \cdot L^{-1}$ value was exceeded have also increased.

Turbidity levels exceeded the Federal value in McQueen Branch (16.7% to 83.3% of samples exceeded 50 JTU), Crouch Branch (66.7% to 100.0%), UTR Creek below McQueen Branch (UTR--Middle) 22.2%, and UTR Creek below Crouch Branch (UTR--Below) 33.3%. Little turbidity data was available for FY-1983; therefore, no pre-construction/post-construction comparison was made.

<u>No rainfall one day before sampling</u>

TSS levels exceeded the Federal value only in McQueen Branch (5.6% of the samples) and Crouch Branch (44.4% to 50.0%; Table II-5). Recommended turbidity was exceeded only in the two construction impacted streams, McQueen and Crouch. No pattern was exhibited for either TSS or turbidity.

CONCLUSIONS AND RECOMMENDATIONS

McQueen Branch is the principal drainage from the DWPF construction site and a tributary of Upper Three Runs (UTR) Creek. After rainfall, total suspended solids (TSS) levels in McQueen Branch were not significantly higher during FY-1987 and FY-1988 than in FY-1986. Turbidity reflected a similar pattern. The TSS pattern was most likely in response to variation in rainfall. Soil moving activities in S- and Z- areas appear to be less important for FY-1987 and 1988. Also, after rainfall TSS levels in McQueen Branch remained significantly higher than UTR Creek or Tinker Creek levels. TSS levels remained significantly higher in McQueen Branch for FY-1987 and 1988 than levels observed prior to construction.

Table II-5. Summary of data exceeding expired proposed Federal criteria for periods of no rainfall one day before sampling for FY-1983 to FY-1988. Percent of data exceeding (%), minimum value exceeding the standards or criteria (min.), maximum value exceeding the standards or criteria (max.) and number of observations exceeding the standards or criteria (N).

	TSS (80 mg·L-1) % (min-max) N	Turbidity (50 JTU) % (min-max) N
UTR--Above		
FY83-FY88	0.0 -- -- --	0.0 -- -- --
Tinker		
FY83-FY88	0.0 -- -- --	0.0 -- -- --
McQueen		
FY83	0.0 -- -- --	0.0 -- -- --
FY84	5.6(233.8)1	16.7(69-390)3
FY85	0.0 -- -- --	5.9(55.5)1
FY86	5.6(105.7)1	22.2(56-115)4
FY87-88	0.0 -- -- --	0.0 -- -- --
UTR--Middle		
FY83-FY88	0.0 -- -- --	0.0 -- -- --
Crouch		
FY83	0.0 -- -- --	Not Sampled
FY84	Not Sampled	Not Sampled
FY85	0.0 -- -- --	33.3(170)1
FY86	44.4(133.3-217.1)4	66.7(130-365)6
FY87	50.0(180.2)1	50.0(350)1
FY88	0.0 -- -- --	0.0 -- -- --
UTR--Below		
FY83-88	0.0 -- -- --	0.0 -- -- --

For periods of no rainfall, TSS levels in McQueen Branch were significantly lower for FY-1987 and FY-1988 than in FY-1986. Turbidity showed a similar pattern. The TSS pattern appears to reflect a decrease in newly started construction activities in the drainage area. After periods of no rain, TSS levels in McQueen Branch were not significantly different in FY-1987 and 1988 than levels observed prior to construction.

Stream profile and flow measurements were initiated at McQueen Branch and Tinker Creek during FY-1986 in order to calculate TSS loading (expressed in kilograms of TSS per day per square kilometer of drainage). After rainfall, the two sites on McQueen Branch were significantly higher than Tinker Creek (unimpacted site). The loading pattern followed the pattern of rainfall. For periods of no rain, the two McQueen Branch sites were not significantly higher than Tinker Creek.

The FY-1983-84 Annual Report concluded that, during periods of heavy rainfall, inputs from McQueen Branch were sufficient to increase the TSS load of UTR Creek below the confluence with McQueen Branch. FY-1986 data supported this statement in two instances. For FY-1987 and FY-1988 McQueen Branch TSS inputs continued to increase TSS in UTR Creek, but Tinker Creek inputs also appeared to be contributing at times during both years. This pattern also held for turbidity and percent ash weight. Because this pattern was also present prior to construction, it is difficult to assess the impact on UTR Creek of these individual rainfall events and DWPF construction.

After rainfall, TSS levels in UTR Creek were not significantly different in FY-1987 and FY-1988 from the portion of UTR Creek unimpacted by the construction compared to the portion of UTR Creek below the construction. For periods of no rainfall, the same patterns of no significant differences were seen for the two portions of the Creek.

TSS and turbidity data were compared with the United States Environmental Protection Agency (USEPA) expired proposed criteria. After rainfall, TSS values exceeded the Federal levels mainly for McQueen Branch and Crouch Branch. The same pattern was true of the turbidity data. FY-1983 (i.e., pre-construction) TSS data were used to establish a background for comparison; the percentage of TSS data from McQueen Branch which exceeded the Federal level was calculated. The data from FY-1985, FY-1986, FY-1987 and FY-1988 exceeded this "background" level. For periods of no rain, TSS and turbidity values exceeded the Federal levels only in McQueen and Crouch branches. The TSS data for FY-1984 and FY-1986 exceeded the pre-construction percentages for McQueen Branch.

It can be assumed that higher TSS levels would be observed in McQueen Branch if erosion control measures (i.e., settling basins, grass seeding, and hay bales) had not been implemented. However, this cannot be accurately assessed since there are no data for a construction-impacted stream during the same time period without control measures.

We recommend that:

1. Sampling for particle size composition of McQueen Branch should be terminated. Based on the two year comparisons no differences were seen between years for sediment composition percents that are closely linked to TSS loads. The data should be retained for possible comparison to after construction data as priorities permit.
2. Consideration should be given to finding ways to increase the efficiency of the three sedimentation basins on McQueen and Crouch Branches. This is based upon: (a) the different patterns of change in TSS and turbidity for the branches (Figures II-2 and II-3) in relation to decline in newly started construction activities and (b) the increasing percentages of

TSS values above the expired proposed Federal criteria for these two branches (Table II-4).

3. Two trends should continue to be examined:

   a. decreasing TSS and turbidity levels in McQueen Branch and Crouch Branch, for times *not* associated with a rain event, and

   b. increasing turbidity in UTR Creek below the construction site, after rain events.

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III. REFUGE PONDS: AN EXPERIMENT IN MITIGATION

Joseph H. K. Pechmann, David E. Scott, and Ruth A. Estes

INTRODUCTION

A Carolina bay (Sun Bay) located on the DWPF site was cleared and filled during FY-1984 as part of DWPF site preparation. Four artificial ponds were constructed on the periphery of S-Area in an experimental attempt to mitigate the impact of the DWPF construction. Colonization and succession of amphibians are being studied at these "refuge ponds" in order to examine the responses of fauna to DWPF construction, and to determine the potential of the ponds for mitigating these impacts. Examination of colonization and succession in newly created or disturbed habitats provides valuable information on ecosystem structure and function as well as the responses of biota to disturbance (e.g. Odum 1969, Simberloff and Wilson 1969, Vitousek and Reiners 1975, Connell 1978, Paine and Levin 1981, Wilbur and Alford 1985). The DWPF project has provided a unique opportunity to investigate this phenomenon.

Amphibians comprised more than 95% of the total non-avian vertebrate fauna at the DWPF site prior to construction (Vitt 1981). Most of the amphibian species found there are primarily terrestrial but must migrate to aquatic habitats to breed. Sun Bay was formerly used by amphibians for breeding and larval development, as are many Carolina bays (Bennett et al. 1979, SREL 1980, Vitt 1981, Gibbons and Semlitsch 1982, Sharitz and Gibbons 1982). Many amphibian species are philopatric, i.e., they return to the same breeding site year after year (Twitty 1959, Shoop 1965, Oldham 1967, Madison and Shoop 1970, Patterson 1978, Semlitsch 1981, Vitt 1981, Vitt et al. 1982). The sensory mechanisms utilized by amphibians to locate their breeding sites have been extensively studied (Twitty 1961, Oldham 1967, Landreth and Ferguson 1967, Taylor and Adler 1973, Hershey and Forester 1979, McGregor and Teska 1989), but remain poorly understood.

Some individuals of some species may migrate one km from their natal pond (unpublished data); however, migration distances are species-specific. Ambystomatid salamanders may not migrate as far from a pond as some newt species (Semlitsch 1983b). Mean migration distances of ambystomatids are much less than one km, and range from 47 - 252 m (Semlitsch 1983b).

It was clear that significant direct amphibian mortality would occur from DWPF construction activities. However, the indirect effects of construction on the amphibian community were uncertain. Would surviving individuals be able to locate Sun Bay after it had been drained and filled,and the surrounding vegetation and topography had been drastically altered? If they did return, would they remain at the former location of Sun Bay although the bay no longer existed? Or would they migrate out in search of another breeding site? Do amphibians have the ability to locate alternative breeding sites by means other than random encounters?

The purpose of this study is to determine whether the artificial refuge ponds built on the periphery of the DWPF site can provide alternative breeding sites for amphibians, thereby mitigating the loss of Sun Bay. These experimental ponds were completed during the latter part of FY-1983. Amphibians moving to and from the ponds are censused by means of terrestrial drift fence with pitfall traps. The former site of Sun Bay is also being assessed for amphibian presence and abundance. The study involves two primary questions: (1) Will the artificial ponds be colonized by adult amphibians, particularly individuals that formerly bred at Sun Bay? and (2) If amphibians breed in the ponds, will the larvae grow, develop, and metamorphose successfully?

This report summarizes the FY-1987 and FY-1988 results. Current data are compared to results from FY-1984, FY-1985, and FY-1986 (Pechmann et al. 1984, Pechmann et al. 1985, Scott et al. 1986), and data from the Rainbow Bay control site collected during FY-1987 and FY-1988 as well as in previous years.

METHODS

Refuge Pond Design

Four refuge ponds (A, B, C, and D) were completed on 20 June 1983 on the periphery of the DWPF construction site (Fig. III-1). Ponds were built between 300 m and 600 m from Sun Bay, which was as close as permitted by DWPF construction plans (including Z-Area). When possible, sites were chosen where water tended to collect naturally, as evidenced by the presence of hydric plants such as mosses. A paved two-lane road lies between Sun Bay and three of the refuge ponds and a powerline right-of-way containing a dirt road lies between the bay and the fourth pond (Fig III-1). The effect of these barriers on amphibian movements is unknown, but it was probably no greater than that of the widespread clearing and grading from construction activities.

Each pond is circular, approximately 16 m in diameter, and has a maximum depth of approximately 1 m. Ponds were originally lined with hard-packed clay so they would collect and hold rainwater. Carolina bays are underlaid by an impervious clay lens (Bryant and McCracken 1964; Schalles 1979), and typically receive no water input other than rain (Sharitz and Gibbons 1982).

Refuge pond water retention was poor during FY-1984 in spite of high rainfall (Pechmann et al. 1984). To rectify this problem fish-grade plastic (CPE) pond liners were installed on 19 November 1984. An overflow pipe was also installed in each pond. After installation of these liners the refuge ponds became permanent ponds. Because the plastic liners initially provided an inert substrate, leaf litter was added to the ponds during February and March 1985. These leaves supplied cover, nutrients, and organic matter for biota.

At the request of DOE, Refuge Pond C (Fig. III-1) was dismantled on 7 June 1985 to accommodate expansion of the planned Z-Area.

Refuge Ponds A and B were each pumped to one-third of their normal depth from 28-29 September 1987 (Pond A from 63 cm to 22 cm, Pond B from 89 cm to 29 cm). Both ponds were dried completely by pumping and hand bailing from 19 October 1987 to 22 October 1987, then allowed to refill with rain beginning 27 October 1987. These manipulations were an attempt to make the hydrologic cycle of these ponds more similar to those of Rainbow Bay and the former Sun Bay.

Sampling Techniques

Amphibian populations were monitored using terrestrial drift fences with pitfall traps (Fig. III-2; SREL 1980, Gibbons and Semlitsch 1982). A drift fence with pitfall traps was constructed encircling each refuge pond on 20-21 June 1983. Traps have since been checked daily and all animals released on the opposite side of the fence, the presumed direction of movement. Data on each amphibian captured were recorded and the majority marked by toe-clipping (see Appendix C for common names). Amphibian populations at the Rainbow Bay control site were monitored in a similar fashion (See Chapter IV for other analyses of these data). By using this technique, the numbers of adults that entered a site to breed, as well as the numbers of juveniles and adults that emigrated from a site, were determined.

Drift fences with pitfall traps were also used to monitor amphibian breeding migrations to the former site of Sun Bay. Four-liter pitfall traps were employed at all Sun Bay fences instead of the 40-liter traps used elsewhere to facilitate rapid

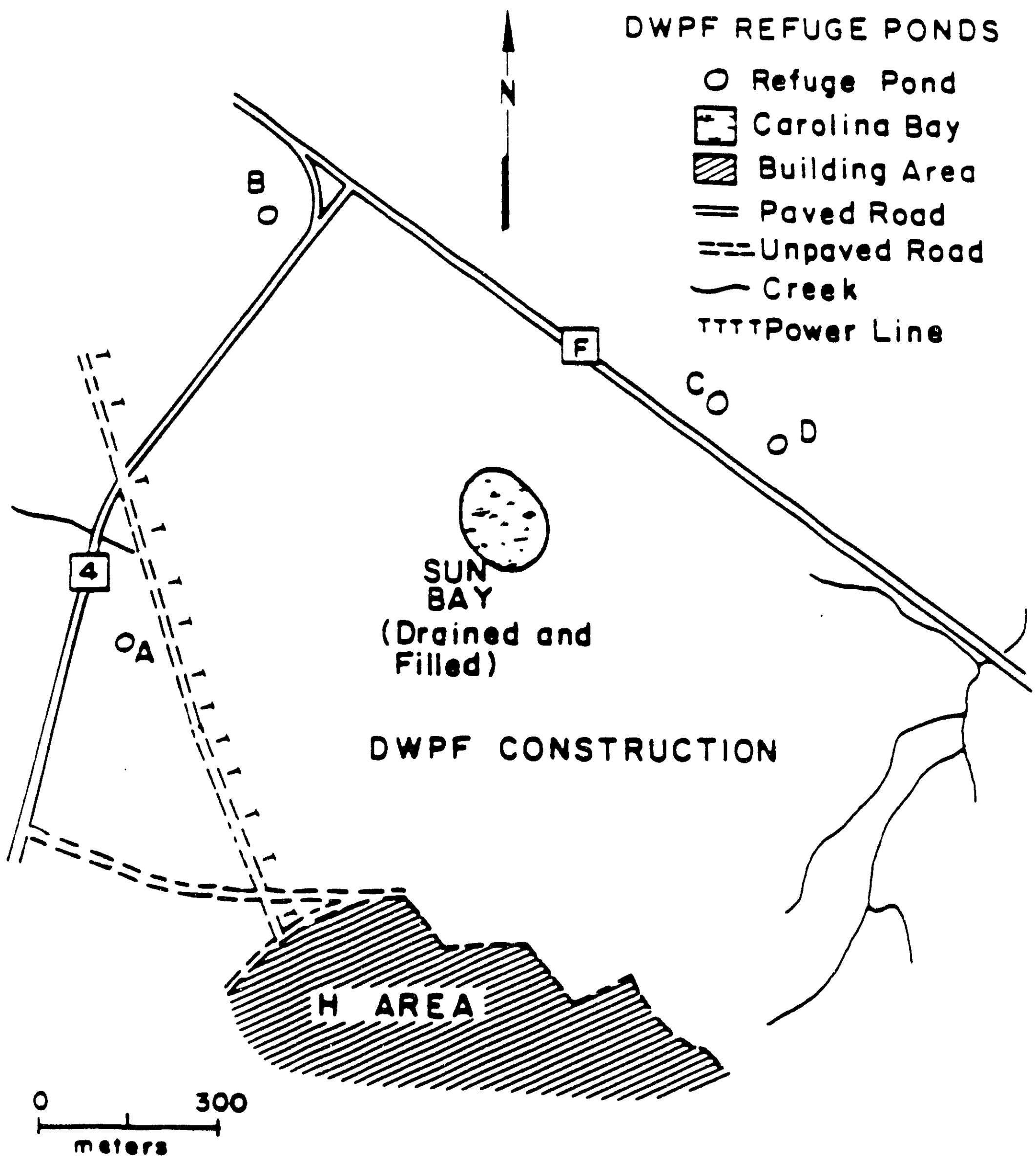

Figure III-1. Locations of DWPF refuge ponds.

removal in the event of interference with construction. During FY-1984, one temporary 50-m drift fence on the northwest side was used to sample Sun Bay from 13 December 1983 to 11 May 1984. Two temporary 50-m fences were erected during FY-1985 on 17 December 1984: one on the northwest side of the former bay, and the other on the northeast. These remained in place until 3 July 1985. During FY-1986 the former site of Sun Bay was sampled in the same manner as in FY-1985. Both the northwest and the northeast fence were rebuilt on 21 November 1985. The fence on the northwest side remained in place until August 29, 1986, when it was removed because of DWPF construction activities. The fence on the northeast side remained in place and was used for sampling throughout FY-1986 and during FY-1987 through 16 September 1987. The Sun Bay site was not sampled during FY-1988 because captures of amphibians at Sun Bay had dwindled to near zero by that time. Differences among sampling methods cloud among-year comparisons of amphibian populations at Sun Bay, but were unavoidable due to the extensive construction activities.

Amphibians at Sun Bay were sampled with minnow traps during FY-1984 before the site was completely drained. Minnow traps were also used to sample the refuge ponds from 10 January 1987 to 15 April 1987.

RESULTS

Biotic Environment

Vegetation succession has occurred at all sites, and a thin stand of old-field grasses and forbs now surrounds each pond. There are annual blooms of filamentous green algae in the ponds. A few emergent sedges (*Scirpus cyperinus*) have taken root in the shallow water along the shores. Aquatic insects, including

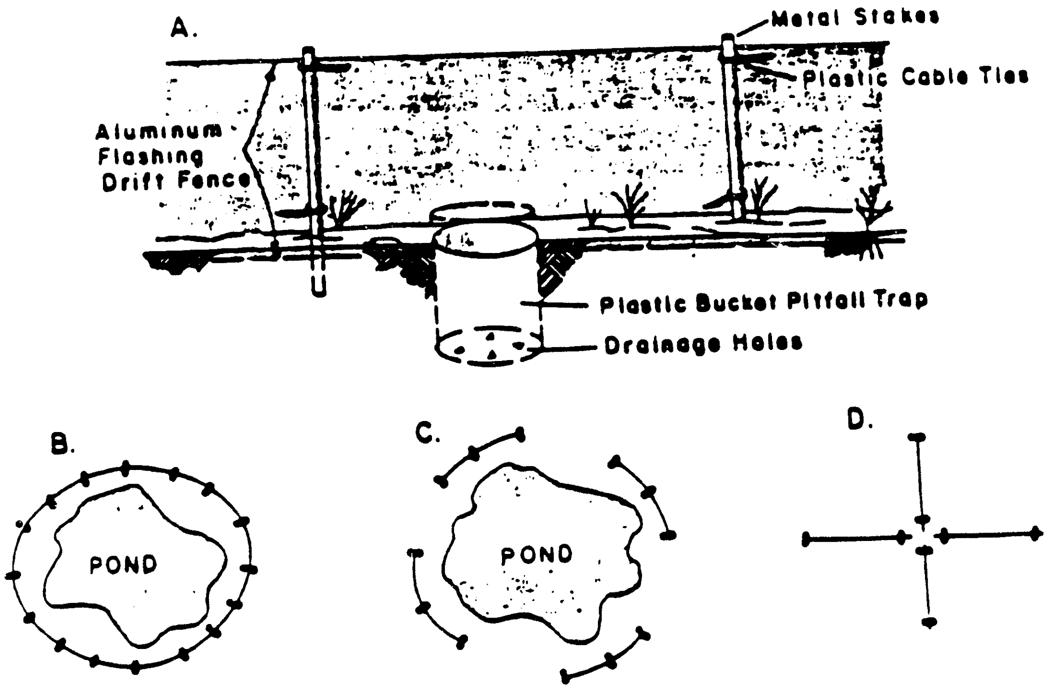

Figure III-2. Design of terrestrial drift fences with pitfall traps used in SREL's DWPF studies (from Gibbons and Semlitsch 1982).

large predaceous Odonata nymphs, are common in the ponds. Crows, sandpipers, and other birds often feed in the water around the edges of the ponds.

Adult Amphibians

In general, frogs and toads colonized the refuge ponds much sooner in the experiment than did the salamanders (Table III-1). Anuran breeding populations were smaller in FY-1987 and FY-1988 than in previous years. Totals in Table III-1 for *Hyla* and *Rana* are minimum estimates because some *Hyla* climb over the drift fences and some *Rana* jump over them.

FY-1986 was the first year that there was any appreciable colonization of the refuge ponds by salamanders. Numbers of adult *Notophthalmus viridescens* and, especially, *Ambystoma talpoideum* that entered the refuge ponds during their FY-1986 breeding seasons were much higher than in any previous year (Table III-1). These higher numbers have persisted during FY-1987 and FY-1988 (Table III-1). However, breeding population sizes of all species continue to be lower at the refuge ponds than at the Rainbow Bay control site (Table III-2).

Only 2 adult amphibians were captured during their breeding season at the former site of Sun Bay in FY-1987 (Table III-3). There were 13 adult amphibians captured during both FY-1985 and FY-1986 at Sun Bay, but the species composition of captures varied between those two years. Many more amphibians were captured at Sun Bay during FY-1984, the year it was drained, than in any subsequent year.

Juvenile Production

In FY-1984 only seven juvenile *Hyla chrysoscelis* and one juvenile *Hyla femoralis* metamorphosed and emigrated from the refuge ponds (see Table V-8 in Pechmann et al. 1984). FY-1985 marked the first year of substantial frog and toad reproduction at the ponds (Table III-4). Although there was much variation among species and ponds, in general FY-1986 and FY-1987 were poor years for anuran recruitment and FY-1988 was again a good year at the ponds. This trend was particularly apparent for *Hyla crucifer* and *Rana utricularia* at Ponds A and B. Two species of frogs produced juveniles for the first time at the refuge ponds during FY-1987: the southern cricket frog, *Acris gryllus*, and the bullfrog, *Rana catesbeiana*. The ornate chorus frog, *Pseudacris ornata*, produced its first cohort of juveniles at the refuge ponds during FY-1988.

Juvenile salamanders were not produced at the refuge ponds until FY-1986 (Table III-4), which was the first year that a relatively large breeding population of adult salamanders colonized the ponds (Table III-1). The total number of metamorphosed juvenile salamanders produced has increased each year since FY-1986 (Table III-4), but only two species of salamanders have produced juveniles at the ponds to date: the mole salamander, *Ambystoma talpoideum*, and the red-spotted newt, *Notophthalmus viridescens*.

If a site does not dry, mole salamander and red-spotted newt larvae can forego metamorphosis and become paedomorphic, that is, remain in the pond and become sexually mature while retaining the larval body form (Semlitsch 1984). Minnow trapping during FY-1987 confirmed that some individuals of both these species follow this life history path at the refuge ponds (Table III-5). Some of the paedomorphic mole salamanders, including a number of those captured in the minnow traps during FY-1987, metamorphosed and emigrated from the ponds following their first reproduction. Overwintering larvae cannot be distinguished from paedomorphic individuals except by dissection, but it is likely that most of the individuals caught in the aquatic traps or that emigrated immediately following the breeding season were sexually mature.

Table III-1. Number of adult amphibians captured entering the refuge ponds during their breeding season from FY-1984 to FY-1988 (total for all four ponds).

Species	1984	1985	1986	1987	1988
Salamanders					
Ambystoma talpoideum	9	4	62	59	33
Ambystoma tigrinum	0	0	1	1	0
Notophthalmus viridescens	3	0	9	8	5
Eurycea quadridigitata	1	1	0	0	0
Frogs and Toads					
Scaphiopus holbrooki	18	11	7	12	5
Bufo terrestris	34	156	161	53	62
Bufo quercicus	4	0	0	0	0
Hyla crucifer	17	27	121	5	28
Hyla femoralis	1	1	0	0	0
Hyla chrysoscelis/versicolor	3	2	1	3	0
Pseudacris nigrita	0	2	2	0	0
Pseudacris ornata	4	4	6	0	10
Gastrophryne carolinensis	68	69	36	34	29
Rana catesbeiana	1	0	1	0	0
Rana clamitans	13	5	7	0	0
Rana utricularia	24	14	98	20	21

Table III-2. Movement of all species of amphibians captured (original and recaptured) in drift fences with pitfall traps at Rainbow Bay during FY-1987 and FY-1988. No juveniles of any species were produced in FY-1988.

Species	1987 Immigrating Adults		1987	1988 Immigrating Adults	
	Male	Female	Juveniles	Male	Female
Salamanders					
Ambystoma talpoideum	1117	807	4778	224	115
Ambystoma opacum	501	394	8401	648	309
Ambystoma tigrinum	15	12	195	4	0
Notophthalmus viridescens	1588	2451	127	1175	794
Plethodon glutinosus	8	3	0	4	5
Eurycea bislineata	0	5	0	0	0
Eurycea quadridigitata	76	40	74	268	309
Frogs and Toads					
Scaphiopus holbrooki	50	17	0	6	1
Bufo terrestris	197	108	0	24	14
Acris gryllus	4	4	0	0	0
Hyla chrysoscelis/versicolor	5	4	1	2	1
Hyla crucifer	27	44	838	1	1
Pseudacris nigrita	--	--	0	2	1
Pseudacris ornata	48	46	2564	32	15
Gastrophryne carolinensis	120	126	0	37	44
Rana catesbeiana	3	1	0	0	0
Rana clamitans	3	3	0	0	0
Rana utricularia	13	9	0	4	2

Table III-3. Number of adult amphibians captured during their breeding season at the former site of Sun Bay from FY-1984 to FY-1987.

Species	1984	1985	1986	1987
Salamanders				
Ambystoma talpoideum	32	1	9	1
Ambystoma opacum	1	0	0	0
Notophthalmus viridescens	17	0	0	0
Frogs and Toads				
Scaphiopus holbrooki	8	1	3	0
Bufo terrestris	9	6	0	0
Hyla crucifer	6	1	0	0
Pseudacris ornata	10	0	0	0
Gastrophryne carolinensis	2	4	0	0
Rana clamitans	2	0	0	0
Rana utricularia	12	0	1	1

Table III-4. Number of amphibian juveniles produced at DWPF refuge ponds during FY-1985 to FY-1988.

Species	Pond A				Pond B				Pond C*	Pond D				Total			
	1985	1986	1987	1988	1985	1986	1987	1988	1985	1985	1986	1987	1988	1985	1986	1987	1988
Ambystoma talpoideum	0	6	1	0	0	32	29	60	0	0	5	202	142	0	43	232	202
Notophthalmus viridescens	0	11	41	85	0	0	2	0	0	0	8	1	57	0	19	44	142
Total Salamanders	0	17	42	85	0	32	31	60	0	0	13	203	199	0	62	276	344
Bufo terrestris	50	1	0	3	16	1	0	0	0	0	14	0	298	66	16	0	301
Acris gryllus	--	--	5	0	--	--	0	0	--	--	--	13	27	0	0	18	27
Hyla crucifer	306	0	0	97	85	3	0	147	313	640	1	1	8	1344	4	1	252
Hyla gratiosa	24	10	31	2	100	15	17	16	0	41	98	5	65	165	123	53	83
Rana catesbeiana	--	--	0	--	--	9	1	--	--	--	0	0	--	--	--	9	1
Pseudacris ornata	0	0	0	1	0	0	0	6	0	0	--	0	0	0	--	0	7
Hyla chrysoscelis/versicolor	59	0	2	0	77	0	2	0	0	6	1	0	1	142	1	4	1
Rana utricularia	19	1	21	287	646	6	0	72	0	0	7	0	0	665	14	21	359
Total Frogs and Toads	458	12	143	389	924	25	28	242	313	687	121	19	399	2382	158	106	1031

*Eliminated 7 June 1985.

Table III-5. Paedomorphic and formerly paedomorphic salamanders captured at the DWPF refuge ponds during FY-1987. Number of individuals captured in aquatic funnel traps from 10 January-15 April 1987, number of those captured in aquatic traps that later metamorphosed and emigrated, and number of individuals first captured when they metamorphosed and emigrated (total for all three ponds).

Species	Aquatic traps	Recapture emigrants	First capture emigrants
Ambystoma talpoideum	39	15	64
Notophthalmus viridescens	40	0	0

DISCUSSION

During FY-1984, the first complete year of our study and of DWPF construction, salamanders continued to return to Sun Bay despite the ongoing construction. The few adult salamanders that entered the refuge ponds during FY-1984 left within a few days (Pechmann et al. 1984). During FY-1985 only one adult salamander was caught at the former site of Sun Bay, and five at the refuge ponds. Lack of opportunities to migrate due to low rainfall during FY-1985 probably contributed to the low number of captures both at these sites and at the Rainbow Bay control site (Pechmann et al. 1985, Pechmann and Semlitsch 1986).

Although much of FY-1986 was also comparatively dry, heavy rains during late November and early December provided salamanders with adequate opportunities to migrate to breeding sites. Record numbers of three salamander species entered Rainbow Bay during FY-1986. Record numbers of two of these species, *Ambystoma talpoideum* and *Notophthalmus viridescens*, also entered the refuge ponds. Far more adults of these two species were captured at the refuge ponds than at the former site of Sun Bay during FY-1986 and FY-1987, although numbers are not directly comparable because DWPF construction precluded comprehensive sampling of Sun Bay. *Ambystoma talpoideum* and *N. viridescens* normally return to breed at the site where they were born (Semlitsch 1981, D. E. Gill, personal communication). Apparently some individuals of these species responded to the elimination of Sun Bay and other disturbances from construction by migrating to the refuge ponds rather than returning to Sun Bay.

Preliminary results indicate that the refuge ponds provide adequate salamander breeding habitat. Both *A. talpoideum* and *N. viridescens* have bred in the refuge ponds since FY-1986, and at least some of their larvae successfully developed through metamorphosis each year. The presence of paedomorphic adults provides additional evidence that the refuge ponds provide favorable habitat for salamanders.

Several species of frogs and toads had colonized the refuge ponds during the first two years of the study (Pechmann et al. 1984, Pechmann et al. 1985). These anuran species may be less philopatric than the salamander species that formerly bred at Sun Bay (personal observations), although differences in speed of travel, response to construction, and other factors might also have contributed to their more rapid colonization. During FY-1986, only three adult *Scaphiopus holbrooki* and one adult *Rana utricularia* were captured during their breeding season at the former site of Sun Bay, and in FY-1987 only one *Rana utricularia* was captured at Sun Bay, whereas hundreds of adult frogs and toads representing ten species migrated during their breeding seasons to the refuge ponds from FY-1986 to FY-1988.

During FY-1984, reproductive success of colonizing frogs and toads was low at the refuge ponds, because the ponds dried frequently, killing any resident tadpoles (Pechmann et al. 1984). FY-1985 was the first year of substantial reproductive success for frogs and toads at the refuge ponds. Over two thousand juveniles representing five species successfully metamorphosed and emigrated from the ponds during FY-1985.

During FY-1986, these same five species also successfully produced metamorphosing juveniles at the three remaining refuge ponds. However, the number produced of each species was much less than in FY-1985, even though breeding population sizes for three of the species were the same or higher (our drift fences capture very few adults of the other two species). The most likely explanation is that predation by salamander larvae (Wilbur et al. 1983) and insects eliminated almost all of their tadpoles during FY-1986. Salamander larvae were not present during FY-1985. Since the ponds were dry at the beginning of FY-1985, but held water continually after that, the number of insect predators was probably much higher in FY-1986 than in FY-1985 (Heyer et al. 1975). This situation continued during FY-1987. Drying of ponds A and B during FY-1988 may have reduced or eliminated both salamander and insect predators in the ponds during winter and early spring contributing to the increased numbers of juvenile anurans produced.

The refuge pond concept appears to have much potential for mitigating the loss or degradation of amphibian breeding habitat on the SRS as well as at other locations. However, results to date indicate that they may provide only partial mitigation. Several species of amphibians that were formerly common at Sun Bay have not yet successfully colonized the refuge ponds, notably *Ambystoma opacum* and *Ambystoma tigrinum* (Semlitsch 1983a). Other species, such as *Pseudacris ornata*, have been slow to colonize. Also, refuge ponds should have a hydrologic cycle similar to that of the original breeding site for maximal success. Ponds that hold water for a shorter or longer period of time each year on the average, or dry more or less frequently than the breeding site they replaced, might support a lower density and diversity of amphibians (Scott et al. 1986). Our experience with the DWPF refuge ponds has demonstrated that building a perched water table system such as that found in Carolina bays (Schalles 1979) is not an easy task. The original pond design did not hold water well enough, but adding pond liners turned them into permanent ponds. Future mitigation efforts should include attempts to mimic more carefully the natural wetland system through construction of larger ponds, alteration of pond depth and configuration, and experimentation with other types of drainage mechanisms. Such approaches must be coupled with continued surveillance of amphibian colonization patterns, as well as the physical and hydrologic aspects of the ponds, in order to evaluate the success of this type of mitigation.

Building replacement wetlands as mitigation for the elimination or degradation of natural wetlands is required in Florida and New Jersey,and in other areas under certain conditions. However, there are very little data to indicate whether or not this is a useful exercise. Studies such as ours will be useful to the Department of Energy as well as other groups in planning how to better manage wetland ecosystems and minimize the impacts of man upon them.

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IV. ENVIRONMENTAL VARIATION, STORAGE EFFECTS, AND THE PERSISTENCE OF THREE SPECIES OF *AMBYSTOMA* AT A TEMPORARY POND

Joseph H.K. Pechmann, David E. Scott, and Raymond D. Semlitsch*

INTRODUCTION

Ecological theory in the 1970s emphasized a steady state, equilibrium view of nature (Patten 1971, May 1973, Roughgarden 1979). Populations, communities, and ecosystems were often modeled as systems of equations (usually linear) that returned to their original stable point following minor to moderate disturbances. This outlook was reflected in the "balance of nature" concept in environmental management and conservation.

The 1980s have witnessed an increasing realization that some ecological systems may be far from equilibrium much of the time, and that natural disturbances themselves may play a key role in maintaining "normal" system dynamics (Strong 1984, Chesson and Case 1986, Wilbur 1987). On the other hand, time delays and non-linearities may result in chaotic population trajectories even in the absence of environmental variation (Schaffer and Kot 1985). Incorporating these concepts into environmental management poses a challenge. How should human impacts on ecosystems be evaluated in light of the importance of natural variation in many systems? For example, human management of wetland water levels must take into account the fact that periodic drying is often a part of the natural hydrologic cycle, and that drying may be important to the maintenance of wetland species diversity (Scott et al. 1986).

This chapter examines how natural environmental variation may interact with other processes to maintain amphibian species diversity at the Rainbow Bay control site. The question of what mechanisms promote the coexistence of species has long

*Collaborating author, Meeman Biological Field Station and Department of Biology, Memphis State University.

been central to community ecology. This question is often asked as "what prevents competitive exclusion among ecologically similar species, in cases where those species do compete?" The classic niche-partitioning theory articulated by Hutchinson (1959) has been replaced by a diversity of both equilibrium and nonequilibrium theories, reviewed by Connell (1978) and Chesson and Case (1986). Both reviews emphasize that more than one of these mechanisms probably operates at once in any particular community.

One of the more intriguing recent nonequilibrium theories is Chesson's storage effect hypothesis (Chesson and Warner 1981, Chesson 1983, Warner and Chesson 1985, Chesson 1986), which suggests that recruitment fluctuations promote species coexistence in communities of long-lived organisms. The conditions under which this mechanism might operate to prevent competitive exclusion are twofold. First, environmental conditions (biotic and abiotic) must vary over time so that each species recruits strongly during some periods at the expense of its competitors, and each of the competitors in turn recruits more strongly during other periods. Each species must have a positive average population growth rate at low density; this is the invasibility criterion of Turelli (1978). The second condition is that each species must have relatively high adult survival so that the population declines only slightly over the periods of poor recruitment. This is called the "storage effect" because strong recruitments are effectively stored in the adult population. Competition among adults must not greatly influence adult survival for the storage effect to operate. The storage effect can also be mediated by traits other than adult longevity, such as storage of seeds in soil seed banks.

The storage effect hypothesis is supported by a number of models (Warner and Chesson 1985), notably the lottery model of competition for space by territorial reef fishes (Chesson and Warner 1981), and Ellner's (1984) seed bank models. Warner and Chesson (1985) provided a "field guide" for assessing the relative importance of the storage effect in promoting the persistence and coexistence of species in a natural community. I am not aware of any published application of this field guide to actual data, other than the single-species examples provided in the original article. The purpose of this paper is to use a ten-year data set to evaluate the contribution of the storage effect to the persistence and coexistence of three congeneric salamander species at Rainbow Bay: *Ambystoma talpoideum* (mole salamander), *A. opacum* (marbled salamander), and *A. tigrinum* (eastern tiger salamander).

NATURAL HISTORY OF *AMBYSTOMA*

Adults of all three species are primarily terrestrial and fossorial, but migrate annually to ponds (often ephemeral ones) to breed. *Ambystoma opacum* migrate to breeding sites from September to November, when the ponds are usually dry. Eggs are deposited in the dry pond bed during October or November, and hatch when the pond fills. Males emigrate from the pond shortly after courtship, but females remain and guard their eggs until the nests are inundated. *Ambystoma talpoideum* and *Ambystoma tigrinum* migrate to breeding ponds on warm rainy nights from November to February. Courtship and oviposition are aquatic, and individuals spend a few days to a few weeks at the breeding site before returning to terrestrial habitats. Mean clutch size is 98 for *A. opacum* (Chapter III), 419 for *A. talpoideum* (terrestrial morph only; Semlitsch 1985b), and 306 for *A. tigrinum* (unpublished data).

Larvae of all three species metamorphose and emigrate from the pond during the spring or summer. Individuals usually return to the pond from which they metamorphosed to breed, *i.e.* they are philopatric, but there is a small amount of exchange among adjacent ponds (unpublished data). If a pond does not dry, some *A. talpoideum* may remain in the pond and become paedomorphic.

STUDY SITE AND SAMPLING METHODS

The study was conducted at Rainbow Bay, Barnwell County, South Carolina, USA, on the United States Department of Energy's Savannah River Site. The pond is a natural depression of unresolved origin called a "Carolina bay" (Sharitz and Gibbons 1982). Three other salamander species (*Siren intermedia, Notophthalmus viridescens,* and *Eurycea quadridigitata*) and eleven species of anurans also breed at Rainbow Bay.

Rainbow Bay is approximately 1 ha in area and has a maximum water depth of 1.04 m. It usually fills with water between December and February and dries between April and September. Vegetation in the pond is dominated by *Scirpus cyperinus, Polygonum* sp., *Panicum verrucosum, Liquidamber styraciflua,* and *Cephalanthus occidentalis.* Rainbow Bay is surrounded by xeric habitats with deep, well-drained sandy soils planted with *Pinus elliottii* and *Pinus taeda; Myrica cerifera* and *Rubus* sp. are common in the understory around the edge of the bay. There are several other *Ambystoma* breeding sites within 1 km of Rainbow Bay, the closest of which is 140 m away.

Ambystoma migrating to and from Rainbow Bay were captured using a terrestrial drift fence with pitfall traps that completely encircled the pond (Gibbons and Semlitsch 1982). The fence was constructed of 50-cm-high aluminum flashing buried 10-15 cm in the ground. Aluminum flashing has a relatively smooth surface and *Ambystoma* have never been observed to climb over or crawl under the drift fence. Forty-liter pitfall traps were buried on each side of the fence at 10-m intervals. Traps were checked daily from 21 September 1978-30 September 1988. All *Ambystoma* were identified and immediately released on the opposite side of the fence.

This technique provided a nearly complete census of adult *Ambystoma* that entered Rainbow Bay each year to breed, and of the number of larvae that successfully metamorphosed and emigrated from the site. Most emigrating juveniles were given a "group" toe-clip mark each year so that annual cohorts could be distinguished when they returned as adults to breed. 1328 emigrating juvenile *A. talpoideum* and 484 emigrating *A. tigrinum* from the 1979 cohort, and >1000 emigrating *A. opacum* from the 1986 cohort, were given individual toe-clip marks. Nearly all (29 male and 10 female) *A. tigrinum* from the 1979 cohort, and some *A. talpoideum* (56 female) and *A. tigrinum* (18 male, 6 female) from the 1982 cohort, had their cohort mark changed to an individual mark when they returned as adults.

ALGORITHM FOR CALCULATING STORAGE EFFECT

Warner and Chesson (1985) provided the following algorithm for calculating the contribution of the storage effect to the mean instantaneous population growth rate, and thus to the persistence of the population. Let $X(t)$ be the adult population size at time t, $\delta(t)$ be the per capita adult death rate at time t and $R(t)$ be the per capita rate of recruitment to the adult population at time t, then

$$X(t+1) = [1-\delta(t)]\,X(t) + R(t)X(t) \qquad (1)$$

$R(t)$ is some function f of a vector of environmental variables at time t, $\xi(t)$, and the population densities of the K species in the system at time t, $X_1(t).....X_k(t)$, and includes any mortality prior to first reproduction:

$$R(t) = f/[\xi(t), X_1(t),.....X_k(t)] \qquad (2)$$

The instantaneous growth rate is the change in log population size from one time to the next, *i.e.*

$$log\,X(t+1) - log\,X(t) = log\,[1-\delta(t) + R(t)] \qquad (3)$$

Warner and Chesson defined the scaled recruitment rate $\rho(t)$ *to be*

$$\rho(t) = R(t)/\delta(t) \qquad (4)$$

Substituting this into equation 3 we obtain

$$\log X(t+1) - \log X(t) = \log\,[1-\delta(t) + \delta(t)\rho(t)] \qquad (5)$$

The storage effect results from the interaction between adult longevity and variation in ρ. The geometric mean of ρ, designated $\bar{\rho}$, would describe population growth if $\delta = 1$ and there were no storage effect. Thus the component of the mean instantaneous population growth rate over n time intervals that does not involve the storage effect is

$$\frac{1}{n}\sum_{j=1}^{n} \log[1-\delta(j)+\delta(j)\bar{\rho}] \qquad (6)$$

The contribution of the storage effects is therefore

$$\frac{1}{n}\sum_{j=1}^{n} \log\,[1-\delta(j)+\delta(j)\rho(j)] - \frac{1}{n}\sum_{j=1}^{n} \log\,[1-\delta(j)+\delta(j)\bar{\rho}] \qquad (7)$$

CALCULATION OF THE STORAGE EFFECT BY THE "INDIVIDUAL METHOD"

Only females were considered in the calculations. The sex ratio in breeding populations was always male-biased, and a male can mate with more than one female, so population dynamics can be modeled satisfactorily without including males. A 1:1 sex ratio at metamorphosis was assumed because the sex of juvenile *Ambystoma* cannot be identified externally. Data for FY-1988 were not used because Rainbow Bay did not fill with water at all during that year, so there was no potential for recruitment by any of the three species. Both breeding population size and the number of metamorphosing juveniles produced per female fluctuated considerably over the ten years of the study for all three species, with only *A. opacum* clearly increasing over time (Table IV-1). Numbers for breeding females

Table IV-1. Female breeding population sizes and juvenile recruitment for the three species of *Ambystoma* at Rainbow Bay.

	A. talpoideum			*A. opacum*			*A. tigrinum*		
Year	Number of breeding females	Total number of metamorphosing juveniles	Number of female metamorphs produced per breeding female*	Number of breeding females	Total number of metamorphosing juveniles	Number of female metamorphs produced per breeding female	Number of breeding females	Total number of metamorphosing juveniles	Number of female metamorphs produced per breeding female
1979	225	4029	8.95	0	0	--	44	1041	11.83
1980	1055	2924	1.39	0	0	--	26	2	0.04
1981	86	3	0.02	2	12	3	8	1	0.06
1982	500	8136	8.14	10	504	25.2	42	410	4.88
1983	827	4624	2.80	15	143	4.77	91	507	2.79
1984	1065	11933	5.60	120	2258	9.41	53	146	1.38
1985	221	0	0	29	0	0	15	0	0
1986	2555	0	0	429	2380	2.77	37	0	0
1987	805	4778	2.97	394	8391	10.65	12	195	8.12

**Assuming a 1:1 sex ratio at metamorphosis.*

include only those that entered the pond to breed each year, which was probably almost always less than the total number of mature females in the population. The number of metamorphs produced per breeding female is likely determined by a complex interaction of numerous biotic and abiotic factors, including predation, competition, and date of pond drying (Wilbur 1987). Complete or nearly complete failures in recruitment were, however, usually associated with early drying of the pond: 7 May in 1981, 4 April in 1985, and 24 April in 1986 (Semlitsch 1987, Pechmann et al. 1989). These failures probably resulted from the pond drying before even fast-growing larvae had reached the minimum size at which metamorphosis is possible (Wilbur and Collins 1973). In years during which the observed recruitment of a species was 0 at Rainbow Bay, 0.02 was used for per capita recruitment as a way to include the low level of migration from adjacent breeding ponds that may occur if recruitment is not zero at all ponds. This value, 0.02, was the lowest non-zero per capita recruitment observed for any species during the study.

Warner and Chesson's storage effect algorithm uses recruitment to the adult population, not juvenile recruitment. Thus the per capita production of metamorphosing juveniles from Table IV-1 had to be corrected for survival to first reproduction. Since age at first reproduction can vary among individuals within a cohort, survival cannot be calculated exactly for cohort-marked groups, but only for those salamanders individually-marked at metamorphosis. These data were available only for the 1979 cohort of *A. talpoideum* and *A. tigrinum*. Values calculated for these species using 1979 juveniles are listed in Table IV-2 as death rate between time of metamorphosis and first reproduction (M). Although M probably varies from cohort to cohort, it was necessary to treat it as a constant given the available data. M could not be calculated at all for *A. opacum*, because metamorphosing juveniles were individually marked only in 1986, and few of these

Table IV-2. Population parameters calculated for females of the three species of *Ambystoma* at Rainbow Bay by two methods. For explanation see text.

	A. talpoideum	*A. opacum*	*A. tigrinum*
Individual method			
Death rate between metamorphosis and first reproduction (M)	0.822	--	0.903
Annual adult death rate(δ)	0.781	--	0.775
Scaled annual recruitment rate to adult population (ρ): geometric mean (range)	0.16(0.005-2.04)	--	0.063(0.003-1.48)
Mean annual population growth rate			
Nonstorage component	-1.07	--	-1.30
Storage component	0.56	--	0.45
Total (storage + nonstorage)	-0.51	--	-0.85
Cohort method			
Death rate between metamorphosis and first reproduction (M)	0.931	0.809	0.954
Annual adult death rate(δ)	0.302	0.353	0.152
Scaled annual recruitment rate to adult population (ρ): geometric mean (range)	0.15(0.005-2.05)	1.60(0.01-13.63)	0.15(0.006-3.55)
Mean annual population growth rate			
Nonstorage component	-0.30	0.192	-0.14
Storage component	0.20	0.37	0.12
Total (storage + nonstorage)	-0.10	0.56	-0.02

have returned to breed to date. The storage effect was therefore calculated for *A. opacum* only by the "cohort method" (see below).

Adult death rate (δ) was calculated using the individually-marked *A. talpoideum* and *A. tigrinum* from the 1979 cohorts, and also those individuals from the 1982 cohorts whose cohort mark was changed to an individual mark in 1983. δ was calculated as the reciprocal of the mean number of times an individual returns to breed, even though individuals that bred more than once did not necessarily do so in consecutive years. Values calculated were 0.781 for *A. talpoideum* and 0.775 for *A. tigrinum* (Table IV-2). Warner and Chesson allowed δ to vary with each time interval, but δ was treated here as a constant since it could not be calculated separately for each year.

Although Warner and Chesson argue that storage effect calculations are properly made only for periods where the population density is relatively low, all nine years were used in my calculations. This was because breeding population size reflects the availability of suitable weather conditions for breeding migrations (warm rainy nights) as well as actual adult population size (Semlitsch 1983, 1985a, Pechmann and Semlitsch 1986). Breeding population sizes therefore tend to be lower in dry years, so that preferentially selecting years when breeding populations were small would have resulted in preferentially selecting dry years, when recruitment was usually poor. The geometric mean and range of the scaled annual recruitment rate to the adult population (ρ) calculated for *A. talpoideum* and *A. tigrinum* using the tabulated values for M and δ and all nine years of data appears in Table IV-2.

No attempt was made to compensate for variation in age at first return in calculations using the individual method. Equation (6) was applied to calculate the non-storage component of the mean annual population growth rate, and equation (7) to calculate the storage component (Table IV-2). Adding both components together provided a value for the total population growth rate (Table IV-2). Despite a positive storage component, total population growth rate was negative for both *A. talpodeum* and *A. tigrinum* over the course of the study. This may reflect the preponderance of droughts over the last ten years. It may also reflect the necessity for utilizing a model with age structure.

CALCULATION OF THE STORAGE EFFECT BY THE "COHORT METHOD"

The number and proportion of females either individually-marked or cohort-marked as juveniles that returned to Rainbow bay to breed at each age from each cohort, including multiple returns, is tabulated for four cohorts of *A. talpoideum* (Table IV-3), two cohorts of *A. opacum* (Table IV-4), and four cohorts of *A. tigrinum* (Table IV-5). Cohorts not tabulated either consisted of only a small number of individuals (Table IV-1), or had only a small number of individuals marked, or were too young for return data to have been collected yet. Although it was shown in the previous section that individual *A. talpoideum* and *A. tigrinum* are not long-lived after first reproduction, but in fact are nearly annuals, Tables IV-3 and IV-5 indicate that the contribution of each cohort to the breeding population is well-spread out over several years. Variation in size at metamorphosis can result in variation in age at first reproduction in amphibians (Smith 1987), including *Ambystoma* (Semlitsch et al. 1988). In addition, weather may play a role as discussed above. Regardless of the cause, there is apparently a storage effect in *Ambystoma* beyond that which results from multiple breedings by single individuals.

For the cohort method of calculating the storage effect for *A. talpoideum* and *A. tigrinum*, the mean proportion that bred at each age was calculated, weighting each cohort equally regardless of its size (Table IV-3) and IV-5). These data were treated as survival data for a cohort having maximum return at age 1 and a constant death rate such that $X = X_0e^{-\delta t}$ where X is the proportion surviving and δ and t are as previously defined. To calculate model parameters, proportions for ages 1 through 5

Table IV-3. Number of female *A. talpoideum* from four cohorts that returned to Rainbow Bay to reproduce at each age, including multiple returns. Proportions are given in parentheses.

Cohort	Number of marked females	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8
1979	664	72 (0.108)	2 (0.003)	24 (0.036)	34 (0.051)	11 (0.017)	0 (0.0)	4 (0.006)	2 (0.003)
1982	4068	173 (0.043)	252 (0.062)	12 (0.003)	172 (0.042)	32 (0.008)			
1983	2312	75 (0.032)	6 (0.003)	64 (0.028)	9 (0.004)				
1984	5966	129 (0.022)	1146 (0.192)	410 (0.069)					
Mean proportion		(0.051)	(0.065)	(0.034)	(0.032)	(0.012)	(0.0)	(0.006)	(0.003)

**Assuming a 1:1 sex ratio at metamorphosis.*

Table IV-4. Number of female *A. opacum* from two cohorts that returned to Rainbow Bay to reproduce at each age, including multiple returns. Proportions are given in parentheses. 1988 data (Age 5 for 1983 cohort, Age 4 for 1984 cohort) are through 19 November 1987.

Cohort	Number of marked female Metamorphs*	Age 1	Age 2	Age 3	Age 4	Age 5
1983	70.5	0 (0.0)	0 (0.0)	15 (0.213)	11 (0.156)	6 (0.085)
1984	1101	10 (0.009)	160 (0.145)	139 (0.126)	73 (0.066)	
Mean proportion		(0.004)	(0.072)	(0.169)	(0.111)	(0.085)
Alternate mean proportion using mean age of maturity of the cohort for age 1†		(0.179)	(0.141)	(0.075)		

**Assuming a 1:1 sex ratio at metamorphosis.*

†Age 3 was used as mean age of maturity for the 1983 cohort, and age 2 was used for the 1984 cohort.

Table IV-5. Number of female *A. tigrinum* from four cohorts that returned to Rainbow Bay to reproduce at each age, including multiple returns. Proportions are given in parentheses.

Cohort	Number of marked female metamorphs*	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8
1979	463	1 (0.002)	0 (0.0)	15 (0.032)	24 (0.052)	11 (0.024)	0 (0.0)	2 (0.004)	2 (0.004)
1982	65.5	7 (0.107)	7 (0.107)	2 (0.031)	3 (0.046)	1 (0.015)			
1983	248	2 (0.008)	0 (0.0)	12 (0.048)	2 (0.008)				
1984	71	3 (0.042)	4 (0.056)	3 (0.042)					
Mean proportion		(0.040)	(0.041)	(0.038)	(0.035)	(0.019)	(0.0)	(0.004)	(0.004)

**Assuming a 1:1 sex ratio at metamorphosis.*

(the ages for which there were at least two replicate cohorts) were log-transformed, and a least-squares regression line calculated through the data points, *i.e.*

$$Log\ X = log\ X_0 - \delta t$$

was fit to the data. The slope of this regression line was converted to a finite rate and used for the adult death rate (δ), and the antilog of the value of the function at age 1 was used for survival to first reproduction (1-M). This method gave higher values for M but much lower values for δ than the "individual method" for *A. talpoideum* and *A. tigrinum* (Table IV-2).

The storage and non-storage components of the mean annual population growth rate were calculated in the same manner as for the "individual method," except that these alternate values of δ and M were used. Using different values for δ and M gives different values of ρ and $\bar{\rho}$ (Table IV-2). The storage component had a greater relative positive impact on the population growth rate of *A. talpoideum* and *A. tigrinum* when the cohort method was used than when the individual method was used. The storage component raises the total population growth rate of *A. tigrinum* to near zero when the cohort method is used, and the total for *A. talpoideum* to -0.16 (compared to -.051 for the individual method). Thus the storage effect may contribute significantly to the persistence of *A. talpoideum* and *A. tigrinum* at Rainbow Bay when factors other than repeated breedings by single individuals are included.

Cohort method calculations for *A. opacum* were less straightforward. Few individuals from the 1984 cohort reproduced before Age 2 (Table IV-4). No individuals from the 1983 cohort reproduced until Age 3. Thus fitting a regression line to the log of the mean proportion returning at each age for *A. opacum* in the manner described above resulted in a positive slope (death rate), and beginning with Age 2 gave a death rate close to zero. An alternate mean proportion was calculated for *A. opacum*, using the mean age of maturity for each cohort as Age 1:

this was Age 3 for the 1983 cohort, and Age 2 for the 1984 cohort (Table IV-4). Fitting a regression line to the logs of these proportions gave M = 0.809 and $\delta = 0.353$. Note that the geometric mean of ρ for *A. opacum* was much higher than that for *A. talpoideum* or *A. tigrinum* calculated by either method. Because of this high $\bar{\rho}$ the non-storage component of the mean annual population growth rate was positive, and total population growth rate was high and positive (Table IV-2). This is compatible with the fact that *A. opacum* has increased from a breeding population size of zero to one of several hundred females over the course of the study. If the higher age of maturity for *A. opacum* was factored into the model, mean annual population growth rate for *A. opacum* would be lower. Nonetheless it seems safe to conclude that the storage effect was not a major contributor to the persistence of *A. opacum* at Rainbow Bay over the past nine years, since the population growth rate was slightly positive without storage, but that the storage component was a major factor in the increase in its population size over time.

THE STORAGE EFFECT ON THE COMMUNITY LEVEL: COEXISTENCE OF SPECIES

Although Warner and Chesson's (1985) "Field guide to the storage effect" provides a precise algorithm for calculating the contribution of the storage effect to population persistence, little detail is provided on how to decide the relative importance of the storage effect to the coexistence of species, *i.e.* its community-level effect. Warner and Chesson simply state that once the storage effect has been shown to contribute to population persistence, "To demonstrate then that the storage effect is a likely mediator of coexistence, it also must be shown that competition is occurring and that recruitment is negatively correlated across different species."

Experiments have not been done to demonstrate whether or not *Ambystoma* larvae compete with each other at Rainbow Bay. There is considerable overlap in the larval diet of the three species, but sampling of food resources suggests that larvae are not food-limited at the site in some years (Taylor et al. 1988). There is experimental evidence of interspecific competition among *Ambystoma* larvae (Wilbur 1972, Stenhouse et al. 1983), but it remains uncertain to what extent predation (Paine 1966, Caswell 1978) and disturbance (Wiens 1977, Connell 1978) might keep population densities in natural ponds below the level at which competitive exclusion would eventually occur.

At Rainbow Bay, there is a positive, not negative, correlation in the number of metamorphosing juveniles produced per breeding female each year between *A. talpoideum* and *A. opacum* ($r = 0.92$, $p < 0.004$, $n = 7$) and between *A. talpoideum* and *A. tigrinum* ($r = 0.75$, $p < 0.021$, $n = 9$), whereas there is no significant correlation between *A. opacum* and *A. tigrinum* ($r = 0.63$, $p < 0.131$, $n = 7$). In general, all three species do better in wet years when the pond dries late (Semlitsch 1987, Pechmann et al. 1989). When partial correlations are done, factoring out date of pond drying, recruitment is still either positively correlated or not significantly correlated across species ($p < 0.003$, $p < 0.023$, and $p < 0.246$, respectively as above). *Ambystoma opacum* produced the highest number of metamorphs per female each year that it bred at the pond (Table IV-1). However during three of the nine years juvenile recruitment was higher for *A. talpoideum* than *A. tigrinum*, during two years juvenile recruitment was higher for *A. tigrinum* than *A. talpoideum,* and during the other four years *A. talpoideum* and *A. tigrinum* were essentially tied. In another paper, Chesson (1986) wrote that "For coexistence it is not necessary that recruitments of the two species should be strictly negatively related.... However, variation in the ratios of recruitment rates for different species in the system does seem to be a general requirement." This variation does indeed seem to be the case for *A. talpoideum* and *A. tigrinum* at Rainbow Bay, so it is possible that their existence is at least in part mediated by recruitment fluctuations and the storage effect, although the relationship between these two species may involve predation by *A. tigrinum* on *A. talpoideum* as well as competition between the two.

CONCLUSIONS

1). The storage effect may contribute to the persistence of *Ambystoma* species at Rainbow Bay if factors other than repeated breedings by a single individual, such as variation in age at first reproduction, are included in the storage calculations. This storage capacity may help buffer *Ambystoma* against disturbances caused by human activities as well as natural environmental fluctuations.

2). Suggested methods for assessing the contribution of recruitment fluctuations and the storage effect to mediating the coexistence of competing species were found to be ambiguous. There are positive, not negative correlations among the three species of *Ambystoma* at Rainbow Bay in juvenile recruitment across years. However, *A. talpoideum* sometimes recruits better than *A. tigrinum,* and sometimes the reverse is true. Thus, the coexistence of *A. talpoideum* and *A. tigrinum* may be in part mediated by the storage effect, if in fact these two species compete.

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APPENDIX A

DWPF Laboratory Data

FY-1983 to FY-1988

By Rainfall/No Rainfall Events

VARIABLE	MEAN	STD ERROR OF MEAN	MAXIMUM VALUE	MINIMUM VALUE	N
------------------------ NO RAINFALL		FY-1983	UTR CK ABOVE ---------------------------		
TSS	3.38	0.26	7.20	1.53	29
LTSS	1.43	0.05	2.10	0.93	29
TURB	6.00	2.00	8.00	4.00	2
LTURB	1.90	0.29	2.20	1.61	2
PTSASH	44.03	1.61	55.62	12.60	29
SCOND	26.36	1.21	35.29	15.25	22
LSCOND	3.29	0.05	3.59	2.79	22
------------------------ NO RAINFALL		FY-1983	TINKER CK ---------------------------		
TSS	3.83	0.39	11.14	1.82	28
LTSS	1.51	0.07	2.50	1.03	28
TURB	1.00	.	1.00	1.00	1
LTURB	0.69	.	0.69	0.69	1
PTSASH	42.64	1.65	52.30	19.40	27
SCOND	49.79	2.27	68.64	32.81	22
LSCOND	3.91	0.04	4.24	3.52	22
------------------------ NO RAINFALL		FY-1983	MCQUEEN BR ---------------------------		
TSS	5.28	0.31	8.56	3.36	21
LTSS	1.81	0.05	2.26	1.47	21
TURB	5.00	0.00	5.00	5.00	2
LTURB	1.79	0.00	1.79	1.79	2
PTSASH	58.11	1.75	69.86	34.12	21
SCOND	59.31	4.16	81.59	32.38	14
LSCOND	4.07	0.07	4.41	3.51	14
------------------------ NO RAINFALL		FY-1983	UTR CK MID. ---------------------------		
TSS	4.05	0.46	8.58	2.02	15
LTSS	1.57	0.08	2.26	1.11	15
TURB	5.00	.	5.00	5.00	1
LTURB	1.79	.	1.79	1.79	1
PTSASH	47.94	0.93	52.67	43.06	13
SCOND	36.65	2.36	46.17	23.11	11
LSCOND	3.61	0.07	3.85	3.18	11
------------------------ NO RAINFALL		FY-1983	CROUCH BR ---------------------------		
TSS	13.16	.	13.16	13.16	1
LTSS	2.65	.	2.65	2.65	1
TURB	.	.	.	.	0
LTURB	.	.	.	.	0
PTSASH	42.25	.	42.25	42.25	1
SCOND	.	.	.	.	0
LSCOND	.	.	.	.	0

VARIABLE	MEAN	STD ERROR OF MEAN	MAXIMUM VALUE	MINIMUM VALUE	N
------------------------ NO RAINFALL FY-1983 UTR BR BELOW ------------------------					
TSS	4.11	0.55	9.02	0.89	15
LTSS	1.56	0.10	2.30	0.64	15
TURB	5.00	.	5.00	5.00	1
LTURB	1.79	.	1.79	1.79	1
PTSASH	45.87	2.54	55.47	15.09	14
SCOND	36.54	2.40	47.33	23.96	12
LSCOND	3.60	0.07	3.88	3.22	12
------------------------ NO RAINFALL FY-1984 UTR CK ABOVE ------------------------					
TSS	3.22	0.33	6.35	1.79	18
LTSS	1.39	0.07	1.99	1.02	18
TURB	3.11	0.42	7.00	1.10	16
LTURB	1.35	0.09	2.08	0.74	16
PTSASH	39.25	1.63	49.48	24.25	16
SCOND	18.74	2.67	36.95	3.42	18
LSCOND	2.79	0.16	3.64	1.49	18
------------------------ NO RAINFALL FY-1984 TINKER CK ------------------------					
TSS	3.65	0.47	6.65	1.32	16
LTSS	1.46	0.10	2.04	0.84	16
TURB	4.99	1.74	27.00	1.00	14
LTURB	1.53	0.17	3.33	0.69	14
PTSASH	39.81	2.31	54.40	24.20	14
SCOND	20.28	2.34	37.87	7.06	16
LSCOND	2.96	0.12	3.66	2.09	16
------------------------ NO RAINFALL FY-1984 MCQUEEN BR ------------------------					
TSS	29.83	12.44	233.82	2.74	18
LTSS	2.80	0.24	5.46	1.32	18
TURB	46.00	23.88	390.00	1.00	16
LTURB	2.74	0.38	5.97	0.69	16
PTSASH	73.04	1.86	85.02	58.12	16
SCOND	45.79	16.92	331.61	11.29	18
LSCOND	3.49	0.15	5.81	2.51	18
------------------------ NO RAINFALL FY-1984 UTR CK MID. ------------------------					
TSS	4.96	0.91	9.52	2.01	9
LTSS	1.69	0.15	2.35	1.10	9
TURB	4.13	0.90	9.00	0.00	8
LTURB	1.48	0.24	2.30	0.00	8
PTSASH	45.44	2.39	53.11	38.71	8
SCOND	21.13	4.01	47.34	5.87	9
LSCOND	2.97	0.18	3.88	1.93	9

VARIABLE	MEAN	STD ERROR OF MEAN	MAXIMUM VALUE	MINIMUM VALUE	N
------------------------ NO RAINFALL	FY-1984	UTR BR BELOW ------------------------			
TSS	5.15	0.81	8.82	2.86	9
LTSS	1.75	0.13	2.28	1.35	9
TURB	4.39	0.42	7.00	3.00	8
LTURB	1.67	0.07	2.08	1.39	8
PTSASH	43.84	2.96	58.28	34.38	8
SCOND	21.19	2.10	35.70	13.75	9
LSCOND	3.07	0.09	3.60	2.69	9
------------------------ NO RAINFALL	FY-1985	UTR CK ABOVE ------------------------			
TSS	7.20	1.78	24.90	1.30	14
LTSS	1.85	0.19	3.25	0.83	14
TURB	3.57	0.71	11.50	1.70	14
LTURB	1.41	0.12	2.53	0.99	14
PTSASH	41.85	3.89	57.00	12.87	14
SCOND	18.12	1.33	31.70	13.50	18
LSCOND	2.92	0.06	3.49	2.67	18
------------------------ NO RAINFALL	FY-1985	TINKER CK ------------------------			
TSS	7.05	1.55	27.60	1.40	17
LTSS	1.87	0.15	3.35	0.88	17
TURB	3.67	0.59	10.80	1.20	17
LTURB	1.44	0.11	2.47	0.79	17
PTSASH	48.70	1.65	59.00	32.77	17
SCOND	27.60	1.45	34.50	15.10	17
LSCOND	3.33	0.06	3.57	2.78	17
------------------------ NO RAINFALL	FY-1985	MCQUEEN BR ------------------------			
TSS	8.87	1.05	21.80	3.90	17
LTSS	2.21	0.10	3.13	1.59	17
TURB	14.57	2.97	55.50	5.20	18
LTURB	2.55	0.14	4.03	1.82	18
PTSASH	69.51	1.92	82.60	47.50	17
SCOND	68.35	9.59	212.80	28.64	18
LSCOND	4.13	0.10	5.37	3.39	18
------------------------ NO RAINFALL	FY-1985	UTR CK MID. ------------------------			
TSS	6.74	1.07	13.00	2.60	9
LTSS	1.97	0.14	2.64	1.28	9
TURB	4.04	0.57	6.90	2.10	8
LTURB	1.57	0.10	2.07	1.13	8
PTSASH	48.00	3.49	57.00	25.09	8
SCOND	19.77	0.44	21.93	18.20	9
LSCOND	3.03	0.02	3.13	2.95	9

VARIABLE	MEAN	STD ERROR OF MEAN	MAXIMUM VALUE	MINIMUM VALUE	N
------------------------	NO RAINFALL	FY-1985	CROUCH BR	------------------------	
TSS	35.00	17.71	70.00	12.80	3
LTSS	3.34	0.48	4.26	2.62	3
TURB	79.77	45.59	170.00	23.30	3
LTURB	4.06	0.57	5.14	3.19	3
PTSASH	85.43	1.50	88.40	83.60	3
SCOND	72.00	8.63	86.90	57.00	3
LSCOND	4.28	0.12	4.48	4.06	3
------------------------	NO RAINFALL	FY-1985	UTR BR BELOW	------------------------	
TSS	5.94	0.86	9.50	3.10	9
LTSS	1.88	0.13	2.35	1.41	9
TURB	4.33	0.66	7.80	2.60	9
LTURB	1.62	0.12	2.17	1.28	9
PTSASH	50.29	1.52	58.00	43.80	9
SCOND	20.66	0.59	24.87	19.10	9
LSCOND	3.07	0.03	3.25	3.00	9
------------------------	NO RAINFALL	FY-1986	UTR CK ABOVE	------------------------	
TSS	8.93	2.39	43.90	2.90	18
LTSS	2.01	0.16	3.80	1.36	18
TURB	4.03	0.96	19.00	1.30	18
LTURB	1.45	0.12	3.00	0.83	18
PTSASH	54.76	1.21	66.70	44.80	18
SCOND	16.99	0.39	20.30	14.40	18
LSCOND	2.89	0.02	3.06	2.73	18
------------------------	NO RAINFALL	FY-1986	TINKER CK	------------------------	
TSS	6.37	1.38	25.60	2.20	17
LTSS	1.82	0.14	3.28	1.16	17
TURB	3.22	0.49	9.70	0.90	17
LTURB	1.36	0.10	2.37	0.64	17
PTSASH	50.28	1.90	56.70	30.80	17
SCOND	33.21	1.01	41.70	26.70	17
LSCOND	3.53	0.03	3.75	3.32	17
------------------------	NO RAINFALL	FY-1986	MCQUEEN BR	------------------------	
TSS	23.93	6.29	105.70	4.60	18
LTSS	2.81	0.21	4.67	1.72	18
TURB	32.86	8.78	115.00	5.10	18
LTURB	2.98	0.24	4.75	1.81	18
PTSASH	80.59	1.74	89.70	65.70	18
SCOND	101.98	12.81	240.80	51.20	18
LSCOND	4.53	0.11	5.49	3.96	18

VARIABLE	MEAN	STD ERROR OF MEAN	MAXIMUM VALUE	MINIMUM VALUE	N
------------------------ NO RAINFALL	FY-1986	UTR CK MID. ----------------------------			
TSS	8.33	2.09	19.20	3.10	8
LTSS	2.07	0.21	3.01	1.41	8
TURB	4.72	1.17	13.00	1.40	9
LTURB	1.61	0.18	2.64	0.88	9
PTSASH	55.47	2.68	68.40	44.40	8
SCOND	23.82	1.00	30.00	20.80	9
LSCOND	3.21	0.04	3.43	3.08	9
------------------------ NO RAINFALL	FY-1986	CROUCH BR ----------------------------			
TSS	105.13	27.51	217.10	16.10	9
LTSS	4.28	0.34	5.38	2.84	9
TURB	177.28	46.07	365.00	19.00	9
LTURB	4.79	0.35	5.90	3.00	9
PTSASH	86.40	1.67	90.00	76.40	9
SCOND	97.33	4.85	125.20	76.70	9
LSCOND	4.58	0.05	4.84	4.35	9
------------------------ NO RAINFALL	FY-1986	UTR BR BELOW ----------------------------			
TSS	7.04	1.33	14.30	3.30	9
LTSS	1.99	0.15	2.73	1.46	9
TURB	4.60	1.09	12.00	2.20	9
LTURB	1.61	0.16	2.56	1.16	9
PTSASH	54.24	2.59	72.10	45.30	9
SCOND	24.68	1.24	33.20	21.70	9
LSCOND	3.24	0.04	3.53	3.12	9
------------------------ NO RAINFALL	FY-1987	UTR CK ABOVE ----------------------------			
TSS	4.15	0.47	5.50	3.30	4
LTSS	1.63	0.09	1.87	1.46	4
TURB	1.30	0.19	1.80	0.90	4
LTURB	0.82	0.08	1.03	0.64	4
PTSASH	50.20	1.69	52.70	45.50	4
SCOND	15.35	0.29	15.90	14.60	4
LSCOND	2.79	0.02	2.83	2.75	4
------------------------ NO RAINFALL	FY-1987	TINKER CR ----------------------------			
TSS	4.18	0.73	6.10	2.80	4
LTSS	1.61	0.14	1.96	1.34	4
TURB	1.60	0.27	2.20	1.00	4
LTURB	0.94	0.11	1.16	0.69	4
PTSASH	49.25	3.29	57.80	42.90	4
SCOND	28.65	2.26	35.00	24.30	4
LSCOND	3.38	0.07	3.58	3.23	4

VARIABLE	MEAN	STD ERROR OF MEAN	MAXIMUM VALUE	MINIMUM VALUE	N
------------------------	NO RAINFALL	FY-1987	MCQUEEN BR	------------------------	
TSS	7.55	1.62	12.00	4.30	4
LTSS	2.09	0.19	2.56	1.67	4
TURB	5.78	1.20	8.40	3.20	4
LTURB	1.86	0.18	2.24	1.44	4
PTSASH	77.33	3.28	85.00	70.00	4
SCOND	71.70	11.69	101.50	54.90	4
LSCOND	4.25	0.16	4.63	3.85	4
------------------------	NO RAINFALL	FY-1987	UTR CK MID.	------------------------	
TSS	4.90	1.20	6.10	3.70	2
LTSS	1.75	0.21	1.96	1.55	2
TURB	1.70	0.40	2.10	1.30	2
LTURB	0.98	0.15	1.13	0.83	2
PTSASH	57.05	2.95	60.00	54.10	2
SCOND	20.85	0.75	21.60	20.10	2
LSCOND	3.08	0.03	3.12	3.05	2
------------------------	NO RAINFALL	FY-1987	CROUCH BR	------------------------	
TSS	93.45	86.75	180.20	6.70	2
LTSS	3.62	1.58	5.20	2.04	2
TURB	179.25	170.75	350.00	8.50	2
LTURB	4.06	1.80	5.86	2.25	2
PTSASH	83.85	6.25	90.10	77.60	2
SCOND	96.45	5.95	102.40	90.50	2
LSCOND	4.58	0.06	4.64	4.52	2
------------------------	NO RAINFALL	FY-1987	UTR BR BELOW	------------------------	
TSS	4.95	0.25	5.20	4.70	2
LTSS	1.78	0.04	1.82	1.74	2
TURB	1.75	0.15	1.90	1.60	2
LTURB	1.01	0.05	1.06	0.96	2
PTSASH	51.60	1.60	53.20	50.00	2
SCOND	22.10	0.50	22.60	21.60	2
LSCOND	3.14	0.02	3.16	3.12	2
------------------------	NO RAINFALL	FY-1988	UTR CK ABOVE	------------------------	
TSS	4.27	0.86	7.90	2.10	6
LTSS	1.60	0.16	2.19	1.13	6
TURB	1.37	0.23	2.20	0.70	6
LTURB	0.84	0.10	1.16	0.53	6
PTSASH	53.30	1.40	57.40	47.60	6
SCOND	14.70	0.33	16.10	14.00	6
LSCOND	2.75	0.02	2.84	2.71	6

VARIABLE	MEAN	STD ERROR OF MEAN	MAXIMUM VALUE	MINIMUM VALUE	N
------------------------	NO RAINFALL	FY-1988	TINKER CK	---------------------------	
TSS	7.82	2.30	17.50	2.50	6
LTSS	2.01	0.25	2.92	1.25	6
TURB	2.63	0.59	4.50	0.80	6
LTURB	1.21	0.18	1.70	0.59	6
PTSASH	57.08	2.99	71.70	52.00	6
SCOND	31.82	1.53	36.10	27.70	6
LSCOND	3.49	0.05	3.61	3.35	6
------------------------	NO RAINFALL	FY-1988	MCQUEEN BR	---------------------------	
TSS	5.80	1.36	10.30	2.10	6
LTSS	1.82	0.20	2.42	1.13	6
TURB	6.90	3.02	21.00	1.70	6
LTURB	1.77	0.32	3.09	0.99	6
PTSASH	75.37	3.14	85.40	66.70	6
SCOND	137.72	46.21	349.00	58.10	6
LSCOND	4.71	0.28	5.86	4.08	6
------------------------	NO RAINFALL	FY-1988	UTR CK MID.	---------------------------	
TSS	5.73	1.27	7.60	3.30	3
LTSS	1.87	0.21	2.15	1.46	3
TURB	2.00	0.51	2.70	1.00	3
LTURB	1.07	0.19	1.31	0.69	3
PTSASH	48.07	7.38	55.60	33.30	3
SCOND	20.80	1.07	22.90	19.40	3
LSCOND	3.08	0.05	3.17	3.02	3
------------------------	NO RAINFALL	FY-1988	CROUCH BR	---------------------------	
TSS	13.60	4.17	18.40	5.30	3
LTSS	2.57	0.36	2.97	1.84	3
TURB	21.37	8.64	36.00	6.10	3
LTURB	2.90	0.49	3.61	1.96	3
PTSASH	78.10	2.42	81.90	73.60	3
SCOND	106.30	12.23	120.00	81.90	3
LSCOND	4.66	0.12	4.80	4.42	3
------------------------	NO RAINFALL	FY-1988	UTR BR BELOW	---------------------------	
TSS	5.43	0.87	6.50	3.70	3
LTSS	1.84	0.15	2.01	1.55	3
TURB	1.90	0.47	2.60	1.00	3
LTURB	1.04	0.18	1.28	0.69	3
PTSASH	53.80	2.66	57.40	48.60	3
SCOND	21.47	1.08	23.50	19.80	3
LSCOND	3.11	0.05	3.20	3.03	3

VARIABLE	MEAN	STD ERROR OF MEAN	MAXIMUM VALUE	MINIMUM VALUE	N
------------------------	RAINFALL	FY-1983	UTR CK ABOVE	---------------------------	
TSS	6.54	0.85	22.20	2.37	24
LTSS	1.92	0.09	3.14	1.21	24
TURB	.	.	.	.	0
LTURB	.	.	.	.	0
PTSASH	49.69	2.30	72.64	15.38	22
SCOND	26.44	1.50	37.09	14.19	19
LSCOND	3.28	0.06	3.64	2.72	19
------------------------	RAINFALL	FY-1983	TINKER CK	---------------------------	
TSS	7.66	1.20	21.79	2.15	20
LTSS	2.02	0.12	3.13	1.15	20
TURB	.	.	.	.	0
LTURB	.	.	.	.	0
PTSASH	46.73	2.84	90.54	30.42	19
SCOND	42.76	2.27	57.31	19.61	17
LSCOND	3.75	0.06	4.07	3.03	17
------------------------	RAINFALL	FY-1983	MCQUEEN BR	---------------------------	
TSS	29.31	9.75	114.97	3.75	14
LTSS	2.81	0.29	4.75	1.56	14
TURB	.	.	.	.	0
LTURB	.	.	.	.	0
PTSASH	69.64	2.97	82.34	54.12	12
SCOND	50.80	3.63	70.36	36.47	9
LSCOND	3.93	0.07	4.27	3.62	9
------------------------	RAINFALL	FY-1983	UTR CK MID.	---------------------------	
TSS	15.14	6.06	73.74	2.87	12
LTSS	2.33	0.25	4.31	1.35	12
TURB	.	.	.	.	0
LTURB	.	.	.	.	0
PTSASH	52.64	3.84	75.96	34.88	11
SCOND	34.27	1.79	42.26	25.84	10
LSCOND	3.55	0.05	3.77	3.29	10
------------------------	RAINFALL	FY-1983	UTR BR BELOW	---------------------------	
TSS	19.49	8.79	105.70	2.71	12
LTSS	2.42	0.29	4.67	1.31	12
TURB	.	.	.	.	0
LTURB	.	.	.	.	0
PTSASH	51.84	4.87	78.03	29.90	11
SCOND	34.12	2.01	44.71	25.31	10
LSCOND	3.54	0.06	3.82	3.27	10

VARIABLE	MEAN	STD ERROR OF MEAN	MAXIMUM VALUE	MINIMUM VALUE	N
------------------------	RAINFALL	FY-1984	UTR CK ABOVE	---------------------------	
TSS	5.57	1.06	8.34	2.08	6
LTSS	1.80	0.19	2.23	1.12	6
TURB	4.00	1.35	9.70	1.00	6
LTURB	1.43	0.27	2.37	0.69	6
PTSASH	47.16	3.60	58.03	35.54	6
SCOND	17.88	2.76	27.48	10.30	6
LSCOND	2.88	0.15	3.35	2.43	6
------------------------	RAINFALL	FY-1984	TINKER CK	---------------------------	
TSS	7.70	2.80	19.76	1.87	6
LTSS	1.91	0.32	3.03	1.06	6
TURB	3.57	0.58	5.60	2.00	6
LTURB	1.48	0.13	1.89	1.10	6
PTSASH	44.06	4.48	61.29	29.89	6
SCOND	18.76	4.34	28.44	5.94	6
LSCOND	2.81	0.28	3.38	1.94	6
------------------------	RAINFALL	FY-1984	MCQUEEN BR	---------------------------	
TSS	20.89	5.46	39.36	7.77	6
LTSS	2.92	0.26	3.70	2.17	6
TURB	26.67	9.17	62.00	5.00	6
LTURB	3.01	0.36	4.14	1.79	6
PTSASH	71.88	2.05	78.91	66.07	6
SCOND	24.05	3.53	33.34	10.74	6
LSCOND	3.16	0.17	3.54	2.46	6
------------------------	RAINFALL	FY-1984	UTR CK MID.	---------------------------	
TSS	8.82	2.96	12.89	3.07	3
LTSS	2.16	0.38	2.63	1.40	3
TURB	4.20	1.64	6.40	1.00	3
LTURB	1.51	0.41	2.00	0.69	3
PTSASH	40.71	6.99	52.33	28.16	3
SCOND	115.62	107.05	329.70	5.89	3
LSCOND	3.41	1.21	5.80	1.93	3
------------------------	RAINFALL	FY-1984	UTR BR BELOW	---------------------------	
TSS	7.54	2.19	9.82	3.16	3
LTSS	2.06	0.32	2.38	1.43	3
TURB	4.57	1.81	6.90	1.00	3
LTURB	1.56	0.44	2.07	0.69	3
PTSASH	47.20	5.90	53.87	35.44	3
SCOND	14.46	6.60	27.43	5.88	3
LSCOND	2.56	0.42	3.35	1.93	3

VARIABLE	MEAN	STD ERROR OF MEAN	MAXIMUM VALUE	MINIMUM VALUE	N
------------------------	RAINFALL	FY-1985	UTR CK ABOVE	----------------------------	
TSS	4.54	0.54	5.70	2.90	5
LTSS	1.69	0.10	1.90	1.36	5
TURB	3.46	0.55	4.40	1.50	5
LTURB	1.46	0.15	1.69	0.92	5
PTSASH	58.26	6.51	75.90	42.70	5
SCOND	17.75	2.83	28.30	11.85	5
LSCOND	2.89	0.14	3.38	2.55	5
------------------------	RAINFALL	FY-1985	TINKER CK	----------------------------	
TSS	6.27	1.23	10.10	2.40	6
LTSS	1.90	0.20	2.41	1.22	6
TURB	4.32	0.42	5.50	2.70	6
LTURB	1.65	0.08	1.87	1.31	6
PTSASH	55.58	7.41	86.20	33.50	6
SCOND	25.47	5.50	34.70	5.93	5
LSCOND	3.14	0.30	3.58	1.94	5
------------------------	RAINFALL	FY-1985	MCQUEEN BR	----------------------------	
TSS	41.92	23.14	152.10	5.60	6
LTSS	3.14	0.48	5.03	1.89	6
TURB	59.12	38.95	252.00	8.00	6
LTURB	3.34	0.49	5.53	2.20	6
PTSASH	74.17	3.51	89.00	65.70	6
SCOND	72.96	16.46	127.40	37.30	5
LSCOND	4.20	0.23	4.86	3.65	5
------------------------	RAINFALL	FY-1985	UTR CK MID.	----------------------------	
TSS	6.10	1.56	9.20	4.20	3
LTSS	1.92	0.21	2.32	1.65	3
TURB	4.07	0.75	5.40	2.80	3
LTURB	1.60	0.15	1.86	1.34	3
PTSASH	60.00	8.80	77.60	51.10	3
SCOND	19.37	0.64	20.20	18.12	3
LSCOND	3.01	0.03	3.05	2.95	3
------------------------	RAINFALL	FY-1985	CROUCH BR	----------------------------	
TSS	65.30	.	65.30	65.30	1
LTSS	4.19	.	4.19	4.19	1
TURB	158.00	.	158.00	158.00	1
LTURB	5.07	.	5.07	5.07	1
PTSASH	86.70	.	86.70	86.70	1
SCOND	71.70	.	71.70	71.70	1
LSCOND	4.29	.	4.29	4.29	1

VARIABLE	MEAN	STD ERROR OF MEAN	MAXIMUM VALUE	MINIMUM VALUE	N
------------------------	RAINFALL	FY-1985	UTR BR BELOW	---------------------------	
TSS	5.83	1.48	8.80	4.30	3
LTSS	1.88	0 20	2.28	1.67	3
TURB	4.87	1.14	7.00	3.10	3
LTURB	1.73	0.19	2.08	1.41	3
PTSASH	58.27	8.08	74.40	49.30	3
SCOND	20.09	1.51	22.80	17.58	3
LSCOND	3.04	0.07	3.17	2.92	3
------------------------	RAINFALL	FY-1985	UTR CK ABOVE	---------------------------	
TSS	12.90	4.49	35.10	6.10	6
LTSS	2.46	0.24	3.59	1.96	6
TURB	5.03	1.01	9.00	2.60	6
LTURB	1.73	0.16	2.30	1.28	6
PTSASH	54.17	1.39	59.20	48.60	6
SCOND	17.78	1.67	25.50	14.90	6
LSCOND	2.92	0.08	3.28	2.77	6
------------------------	RAINFALL	FY-1985	TINKER CK	---------------------------	
TSS	10.65	1.58	15.60	5.80	6
LTSS	2.41	0.14	2.81	1.92	6
TURB	4.70	0.52	6.50	3.00	6
LTURB	1.72	0.09	2.01	1.39	6
PTSASH	51.02	0.90	53.40	47.70	6
SCOND	39.48	6.86	71.50	27.40	6
LSCOND	3.64	0.14	4.28	3.35	6
------------------------	RAINFALL	FY-1985	MCQUEEN BR	---------------------------	
TSS	73.93	19.92	143.20	25.90	6
LTSS	4.14	0.27	4.97	3.29	6
TURB	127.50	36.84	260.00	39.00	6
LTURB	4.64	0.29	5.56	3.69	6
PTSASH	87.93	1.17	90.00	82.20	6
SCOND	84.10	7.36	109.90	60.70	6
LSCOND	4.42	0.09	4.71	4.12	6
------------------------	RAINFALL	FY-1985	UTR CK MID.	---------------------------	
TSS	16.43	4.73	25.60	9.80	3
LTSS	2.79	0.26	3.28	2.38	3
TURB	9.30	4.35	18.00	4.80	3
LTURB	2.17	0.39	2.94	1.76	3
PTSASH	55.53	1.15	57.80	54.10	3
SCOND	28.50	6.75	42.00	21.40	3
LSCOND	3.34	0.21	3.76	3.11	3

VARIABLE	MEAN	STD ERROR OF MEAN	MAXIMUM VALUE	MINIMUM VALUE	N
-----------------------RAINFALL		FY-1986	CROUCH BR-------------------------		
TSS	60.40	19.92	93.80	24.90	3
LTSS	3.99	0.38	4.55	3.25	3
TURB	123.33	46.67	210.00	50.00	3
LTURB	4.66	0.41	a5.35	3.93	3
PTSASH	87.90	0.89	89.20	86.20	3
SCOND	204.00	4.51	111.50	95.90	3
LSCOND	4.65	0.04	4.72	4.57	3
-----------------------RAINFALL		FY-1986	UTR BR BELOW---------------------		
TSS	16.07	3.35	22.40	11.00	3
LTSS	2.80	0.19	3.15	2.48	3
TURB	9.60	4.72	19.00	4.10	3
LTURB	2.18	0.42	3.00	1.63	3
PTSASH	56.48	2.14	60.70	54.10	3
SCOND	27.73	4.32	36.30	22.50	3
LSCOND	3.34	0.14	3.62	3.16	3
-----------------------RAINFALL		FY-1987	UTR CK ABOVE---------------------		
TSS	6.70	0.65	15.90	3.10	20
LTSS	1.98	0.08	2.83	1.41	20
TURB	3.13	0.34	7.30	1.20	20
LTURB	1.36	0.07	2.12	0.79	20
PTSASH	52.94	0.88	61.50	45.20	20
SCOND	16.33	0.45	21.70	13.80	20
LSCOND	2.85	0.02	3.12	2.69	20
-----------------------RAINFALL		FY-1987	TINKER CK---------------------		
TSS	9.62	1.64	34.20	2.10	20
LTSS	2.19	0.13	3.56	1.13	20
TURB	4.49	1.06	24.00	1.50	20
LTURB	1.55	0.11	3.22	0.92	20
PTSASH	51.79	0.75	58.30	46.90	20
SCOND	28.92	0.86	35.70	24.30	20
LSCOND	3.39	0.03	3.60	3.23	20
-----------------------RAINFALL		FY-1987	MCQUEEN BR-------------------------		
TSS	121.46	40.96	655.00	5.30	19
LTSS	3.83	0.34	6.49	1.84	19
TURB	159.48	46.17	650.00	4.40	19
LTURB	4.09	0.37	6.48	1.69	19
PTSASH	86.54	1.33	97.20	75.30	19
SCOND	69.61	5.31	118.30	39.80	19
LSCOND	4.21	0.07	4.78	3.71	19

VARIABLE	MEAN	STD ERROR OF MEAN	MAXIMUM VALUE	MINIMUM VALUE	N
----------------------RAINFALL		FY-1987	UTR CK MID.----------------------		
TSS	10.21	2.36	29.10	3.90	10
LTSS	2.26	0.17	3.40	1.59	10
TURB	7.31	2.62	29.00	2.10	10
LTURB	1.83	0.23	3.40	1.13	10
PTSASH	59.02	1.86	71.30	51.70	10
SCOND	22.81	0.66	25.90	20.10	10
LSCOND	3.17	0.03	3.29	3.05	10
----------------------RAINFALL		FY-1987	CROUCH BR--------------------		
TSS	82.17	20.15	215.50	12.10	9
LTSS	4.15	0.28	5.38	2.57	9
TURB	152.33	36.52	390.00	21.00	9
LTURB	4.76	0.29	5.97	3.09	9
PTSASH	88.36	1.05	92.90	82.60	9
SCOND	99.53	6.67	127.20	61.80	9
LSCOND	4.59	0.07	4.85	4.14	9
----------------------RAINFALL		FY-1987	UTR BR BELOW--------------------		
TSS	13.55	3.15	36.80	3.90	10
LTSS	2.50	0.20	3.63	1.59	10
TURB	10.82	3.89	40.00	2.30	10
LTURB	2.08	0.28	3.71	1.19	10
PTSASH	63.52	2.19	76.10	57.00	9
SCOND	23.21	0.67	26.30	20.60	10
LSCOND	3.18	0.03	3.31	3.07	10
----------------------RAINFALL		FY-1988	UTR CK ABOVE--------------------		
TSS	9.42	1.52	22.40	3.10	18
LTSS	2.16	0.15	3.15	1.41	18
TURB	5.76	1.45	24.00	1.20	18
LTURB	1.61	0.18	3.22	0.79	18
PTSASH	56.99	0.94	65.20	51.20	18
SCOND	17.78	0.81	26.90	14.40	18
LSCOND	2.92	0.04	3.33	2.73	18
----------------------RAINFALL		FY-1988	TINKER CK--------------------		
TSS	15.93	3.32	45.00	2.00	18
LTSS	2.47	0.21	3.83	1.10	18
TURB	8.90	2.65	45.00	1.40	18
LTURB	1.83	0.22	3.83	0.88	18
PTSASH	55.14	1.56	72.40	48.10	18
SCOND	33.99	2.14	55.30	22.30	18
LSCOND	3.53	0.06	4.03	3.15	18

VARIABLE	MEAN	STD ERROR OF MEAN	MAXIMUM VALUE	MINIMUM VALUE	N
----------RAINFALL		FY-1988	MCQUEEN BR----------		
TSS	129.06	25.84	331.20	4.80	18
LTSS	4.31	0.30	5.81	1.76	18
TURB	189.11	36.40	495.00	3.20	18
LTURB	4.66	0.33	6.21	1.44	18
PTSASH	87.29	0.74	91.10	79.20	18
SCOND	141.94	31.36	510.00	46.70	18
LSCOND	4.65	0.18	6.24	3.86	18
----------RAINFALL		FY-1988	UTR CK MID.----------		
TSS	21.40	7.28	66.90	4.30	9
LTSS	2.70	0.32	4.22	1.67	9
TURB	23.88	9.21	74.00	1.70	9
LTURB	2.46	0.46	4.32	0.99	9
PTSASH	66.28	3.38	78.90	53.50	9
SCOND	26.60	2.21	38.40	21.50	9
LSCOND	3.29	0.08	3.67	3.11	9
----------RAINFALL		FY-1988	CROUCH BR----------		
TSS	182.30	39.78	398.30	8.40	9
LTSS	4.87	0.37	5.99	2.24	9
TURB	316.51	65.33	670.00	8.60	9
LTURB	5.38	0.42	6.51	2.26	9
PTSASH	89.46	0.85	92.60	83.30	9
SCOND	112.44	6.10	128.50	72.30	9
LSCOND	4.72	0.06	4.86	4.29	9
----------RAINFALL		FY-1988	UTR CK ABOVE----------		
TSS	26.61	8.41	66.60	4.10	9
LTSS	2.85	0.36	4.21	1.63	9
TURB	29.41	10.70	78.50	1.80	9
LTURB	2.60	0.49	4.38	1.03	9
PTSASH	67.82	3.17	81.10	56.10	9
SCOND	28.29	2.43	40.20	22.30	9
LSCOND	3.35	0.08	3.72	3.15	9

CODE: TSS = Total suspended solids (mg/L).
LTSS = Log of TSS.
TURB: Turbudity (NTU).
LTURB = Log of turbidity.
PTSASH = % ash weight.
SCOND = Specific conductance (umhos/cm).
LSCOND = Log of specific conductance.

APPENDIX B

DWPF TSS Loading Data

FY-1986 to FY-1988

By Rainfall/No Rainfall Events

VARIABLE	MEAN	STD ERROR OF MEAN	MAXIMUM VALUE	MINIMUM VALUE	N
------------------NO RAINFALL		FY-1986	MCQUEEN BR UPPER----------------		
KGPDPKM2	15.95	6.84	63.39	1.13	9
LLPDPA	2.20	0.40	4.17	0.75	9
-----------------NO RAINFALL		FY-1986	MCQUEEN BR LOWER----------------		
KGPDPKM2	6.49	2.75	27.88	1.87	9
LLPDPA	1.70	0.24	3.36	1.06	9
------------------NO RAINFALL		FY-1987	TINKER CK----------------------		
KGPDPKM2	4.30	1.04	7.22	1.11	7
LLPDPA	1.52	0.23	2.11	0.74	7
------------------NO RAINFALL		FY-1987	MCQUEEN BR UPPER----------------		
KGPDPKM2	9.85	7.27	17.12	2.59	2
LLPDPA	2.09	0.81	2.90	1.28	2
------------------NO RAINFALL		FY-1987	MCQUEEN BR LOWER---------------		
KGPDPKM2	4.75	3.14	7.89	1.61	2
LLPDPA	1.57	0.61	2.18	0.96	2
------------------NO RAINFALL		FY-1987	TINKER CK---------------------		
KGPDPKM2	5.45	0.28	5.73	5.17	2
LLPDPA	1.86	0.04	1.91	1.82	2
------------------NO RAINFALL		FY-1987	MCQUEEN BR UPPER----------------		
KGPDPKM2	2.59	1.05	4.64	1.22	3
LLPDPA	1.20	0.28	1.73	0.80	3
------------------NO RAINFALL		FY-1987	MCQUEEN BR LOWER----------------		
KGPDPKM2	1.77	0.68	3.03	0.67	3
LLPDPA	0.96	0.25	1.39	0.52	3
------------------NO RAINFALL		FY-1987	TINKER CK---------------------		
KGPDPKM2	6.78	3.33	13.41	2.99	3
LLPDPA	1.88	0.40	2.67	1.38	3

VARIABLE	MEAN	STD ERROR OF MEAN	MAXIMUM VALUE	MINIMUM VALUE	N
----------------------RAINFALL		FY-1986		MCQUEEN BR UPPER----------------	
KGPDPKM2	105.53	30.86	163.85	58.88	3
LLPDPA	4.58	0.29	5.11	4.089	3
---------------------RAINFALL		FY-1986		MCQUEEN BR LOWER----------------	
KGPDPKM2	13.61	3.53	20.03	7.83	3
LLPDPA	2.62	0.25	3.05	2.18	3
----------------------RAINFALL		FY-1987		TINKER CK----------------------	
KGPDPKM2	21.51	13.64	48.17	3.18	3
LLPDPA	2.66	0.71	3.90	1.43	3
----------------------RAINFALL		FY-1987		MCQUEEN BR UPPER----------------	
KGPDPKM2	531.04	396.99	4051.00	3.45	10
LLPDPA	4.17	0.71	8.31	1.49	10
----------------------RAINFALL		FY-1987		MCQUEEN BR LOWER---------------	
KGPDPKM2	187.43	107.56	808.15	2.99	9
LLPDPA	3.62	0.66	6.70	1.38	9
----------------------RAINFALL		FY-1987		TINKER CK----------------------	
KGPDPKM2	12.60	2.24	24.94	2.94	8
LLPDPA	2.50	0.19	3.26	1.37	8
----------------------RAINFALL		FY-1987		MCQUEEN BR UPPER----------------	
KGPDPKM2	700.31	466.35	4370.16	10.99	9
LLPDPA	5.13	0.62	7.69	1.17	19
----------------------RAINFALL		FY-1987		MCQUEEN BR LOWER----------------	
KGPDPKM2	354.21	231.96	2177.96	2.23	9
LLPDPA	4.32	0.69	7.69	1.17	9
-----------------------RAINFALL		FY-1987		TINKER CK----------------------	
KGPDPKM2	46.81	17.21	146.87	4.51	9
LLPDPA	3.19	0.43	5.00	1.71	9

APPENDIX C

Amphibians Found at
Rainbow Bay, Sun Bay, and the Refuge Ponds

Salamanders

Ambystoma opacum	marbled salamander
A. talpoideum	mole salamander
A. t. tigrinum	eastern tiger salamander
Eurycea bislineata cirrigera	southern two-lined salamander
E. longicauda guttolineata	three-lined salamander
E. quadridigitata	dwarf salamander
Notophthalmus v. viridescens	red-spotted newt
Plethodon g. glutinosus	slimy salamander
Pseudotriton m. montanus	eastern mud salamander
P. ruber vioscai	southern red salamander
Siren intermedia	lesser siren

Toads

Bufo terrestris	southern toad
B. quercicus	oak toad
Gastrophryne carolinensis	eastern narrow-mouthed toad
Scaphiopus h. holbrooki	eastern spadefoot toad

Tree frogs

Hyla cinerea	green treefrog
H. c. crucifer	northern spring peeper
H. femoralis	pine woods treefrog
H. gratiosa	barking treefrog
H. squirella	squirrel treefrog
H. versicolor and/or *chrysoscelis*	gray treefrog

Other Frogs

Acris g. gryllus	southern cricket frog
Pseudacris n. nigrita	southern chorus frog
P. ornata	ornate chorus frog
Rana areolata capito	Carolina gopher frog
R. catesbeiana	bullfrog
R. c. clamitans	bronze frog
R. utricularia	southern leopard frog

END

DATE FILMED

12/06/91