FLOOD-INDUCED BACKWATER REJUVENATION ALONG THE COLORADO RIVER IN GRAND CANYON, ARIZONA: 1996 FINAL REPORT

by

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1 January 1997

Submitted To:

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ACKNOWLEDGEMENTS

We thank Mr. David Wegner and the Glen Canyon Environmental Studies Program staff for all of their assistance during this project. Without their support and assistance this project would not have been possible. The National Park Service permitted this work to be undertaken. The Northern Arizona University Sandbar Erosion staff are also warmly thanked for their assistance. Field assistants and volunteers included studebts and faculty of Arizona State University and Northern Arizona University. The project was administratively overseen by the National Park Service.

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INTRODUCTION

Colorado River backwaters downstream from Glen Canyon Dam are biologically productive, low velocity, shoreline habitats that warm daily and seasonally, and may serve as essential rearing environments for young fish. In Grand Canyon, backwaters typically exist at low discharges when exposed sand bars block recirculating flow in eddies. The size and backwater distribution depends on the size of the sand bars in a channel expansion. Recent studies demonstrate that backwater habitats have decreased in area and number under Interim Flows from Glen Canyon Dam in Grand Canyon. A high flow was planned from Glen Canyon Dam in March/April 1996 to rejuvenate sand bars and backwater habitats.

In this study, we present data and limited analyses of the extent of physical and biological rejuvenation of selected Colorado River backwater habitats resulting from the 1996 Bureau of Reclamation Test Flow from Glen Canyon Dam. We emphasize a multidisciplinary approach to understanding fish nursery habitat impacts during the 1996 growing season. Our specific objectives in 1996 were to collect and compile data on Test Flow related-changes in geomorphology, geochemistry, warming patterns, the fisheries food base, fish diet and fish distribution. This is largely a methods and data report on Test Flow impacts on one study site (Mile 55.5R). More refined syntheses are planned for the 1997 report.

METHODS, RESULTS AND DISCUSSION

Geomorphology

Return current channels are Type I backwater nursery habitats (McGuinn-Robbins 1995), and develop as a result of high flows reworking sediment deposits associated with tributary debris fans. Topographic and bathymetric survey data were collected at the 55.5 site in March (pre-flood), April (post-flood) and September (6 mo. post-flood). These data demonstrate that 54,829 m^3 of sediment was removed from the channel (constriction to base of Mile 55.5R bar at stages <226 m^3/s); 13,962 m^3 were removed from the eddy (coupled with a 1,744 m^2 eddy area increase) below that same stage; and the bar aggraded 4,684 m^3 above that stage (with a concomitant decrease in area of 1,846 m^2; Figs. 1a.1-10). These data demonstrate that no more than 4,684 m^3 of sediment (6.8%) of the total 68,791 m^3 of sediment moved during the Test Flow contributed to bar building. Much of the aggrading sediment may have been derived from upstream sources, not the local eddy complex, thus much less than 6.8% of the sediment locally stored may be used in eddy bar building.

We measured volumetric changes of the long-linear RCC at Mile 55.5R. This is a typical Colorado River Type I backwater (McGuinn-Robbins 1995). Hypsometric analyses revealed that backwater volume decreased by at least 20% as a result of the Test Flow.

The topography of the Mile 55.5R bar continued to change througouth the 1996 growing season. By mid-July the eddy had refilled with sand. The prominent reattachment ramp failed in late summer, probably because resumption of normal flows left the base of the newly formed Test Flow reattachment ramp exposed to direct current, undercutting that feature. A new, low stage RCC developed in the refilled eddy. Infilling of our RCC study backwater was not appreciable in 1996, probably because of low silt input from the Paria River.

Groundwater Geochemistry

Groundwater geochemistry may play a significant role in local nutrient dynamics, and therefore fisheries foodbase development, as well as affecting system-wide nutrient spiraling. We used the Glen Canyon Dam controlled release to test the hypothesis that flooding results in the biogeochemical rejuvenation of Colorado River ecosystems through the burial and accelerated decomposition of organic material. We sited 44 wells (1.5, 3 and 6 m deep) at beaches with RCC's at miles -6.5R, 55.5R, and 194L. We sampled ground and surface waters immediately before, immediately after, and one month, two months, and six months after the Test Flow. Field analyses included pH, specific conductance , temperature, nitrate, nitrite, ammonium, and dissolved oxygen (DO). Laboratory analyses included measurement of non-purgeable organic carbon (NPOC) and orthophosphate.

The Test Flow buried living and detrital organic material under 0.2 to 1.8 m of well sorted fine sand at the study sites. We did not find any evidence of scour in the RCCs at any site. Casual observation of RCCs other than our sites immediately after the recession of the Test Flow further supported this observation. Established RCCs lost depth, width and length. New RCCs that developed behind new reattachment bars were ephemeral and were already eroding one day after the end of the post-Test Flow 226 m^3/s constant flow. The amount of depostion varied between turbidity segments (Stevens et al. in press), with the least amount of deposition at Mile -6.5R and the greatest deposition at Mile 194L.

Pre-Test Flow surface and groundwater samples were collected at miles -6.5R (3/23/96, 45L (3/3/96), 55.5R (3/12/96) and 65R (3/14/96). Post-event samples were collected at miles -6.5R (4/27/96), 55R (4/2/96,4/3/96,4/5/96,4/6/96,4/7/96,6/18/96, and 10/29/96), and 194L (6/26/96 and 11/08/96).

Groundwater in all beaches increased in concentrations of NPOC after the flood ranging from 85-278% (mean concentrations from all beaches = 4.95+/-1.72 mg/L before; 22.5+/-21.4 mg/L after the event). NPOC concentrations at Mile -6.5R increased from 3.95 (+/- 1.7) to 7.32 (+/-10.5, Fig. 2a. 1) and had not recovered by 228 days after recession. NPOC concentrations at Mile 55.5R increased gradually during recession and had doubled (to 22.5 mg/L) by June of 1996 (Fig. 2a.2). All groundwaters show increases in ammonium ranging from 79 to 617% (average from all beaches = 0.80+/-1.21 mg/L before; 5.82+/- 2.67 mg/L after the event). At Mile -6.5R, ammonium concentrations continued to increase through the summer of 1996. Previous work at Mile -6.5R documented slight decreases in ammonium between spring and summer (Parnell et al. 1996). Ammonium concentration increases at Mile 55.5R began with the Test Flow recession and continued through the growing season. Ammonium levels are still elevated in the fall of 1996. The large spatial variability of ammonium concentrations resulted in high variance; however, increased levels in individual wells were significant. Significant decreases in dissolved oxygen (DO) concentrations in bar-stored groundwater occurred at miles -6.5R and 55.5R. Increased ammonium and NPOC and decreased DO are consistent with increasing rates of microbial respiration in these sandbars.

Average orthophosphate concentrations decreased at Mile -6.5R after the flood, and then increased in the fall. This was attributable to increases at only a few wells. Orthophosphate concentrations decreased at Mile 55.5R after the Test Flow and remained low thereafter.

Surface waters in the RCC have highly variable NPOC concentrations. Averages for samples taken at Mile -6.5R and Mile 55.5R increased through the autumn, 1996. Nitrate concentrations in the RCC increased through the summer and decreased through the fall. Increasing groundwater NPOC are reflected in increases in the RCC, which increased local mainstream concentrations.

Mainstream surface water orthophosphate concentrations did not appear to have been altered by the flood event. Changes in main stem surface water NPOC concentrations can be attributed to seasonal conditions and conditions of flow from Glen Canyon Dam. In particular, NPOC increased in the mainstream significantly between the summer and fall at miles -6.5R and 55.5R. Because groundwater flow rates seldom exceed 0.5 m/d, low flows with duration of weeks are required to change groundwater flow patterns and increase groundwater flux into the mainstream. NPOC concentrations in the Glen Canyon reach were low, and increased downstream. Our data suggest that NPOC is delivered to the mainstream by groundwater draining from alluvial deposits.

Because ammonium is converted to oxidized species in the presence of atmospheric oxygen, the large concentrations of ammonium in bar-stored groundwater are not reflected in surface waters. Dissolved inorganic nitrogen in surface waters is predominantly nitrate and nitrite. Nitrate increases in mainstream water are minimal and were not noticeably different than seasonal increases noted at the study sites in previous years (Bennett et al. 1996).

Orthophosphate concentrations in the Glen Canyon reach and at Mile 55.5R did not vary as a function of the 1996 Test Flow.

Hydrogeology

Drive-point wells were installed to quantify nutrient storage and mobilization in the reattachment bar and to determine temporal variations in hydraulic conductivity during one visit to the backwater before, and three visits after, the Test Flow. Hydraulic conductivity measurements were conducted with a pneumatic-slug test on the wells. Water levels were measured in a network of 12 wells and river stages were measured at two gages in the mainstream and at two gages in the backwater during each visit. The $\leq$ 1.8 m of sediment deposited on the Mile 55.5R reattachment bar during the Test Flow compressed the sediments, reducing the hydraulic conductivity.

Climate

Backwaters provide thermal refugia for young fish, and thermal development occurs on diel and seasonal time scales. Climate measurements were made at the Mile 55.5R site during 2-4 d site visits in March, June, and September, including backwater and river water temperature, air temperature, wind speed, relative humidity, net radiation, soil heat flux, and cloud cover. Additional climate data were collected at critical points throughout the day in March, April, June, July, September, and October.

We studied three zones in and around the RCC backwater: the relatively isolate head, the mixing zone, and the river. The BB transect was selected as a relatively isolated cross-section of the backwater. Water temperature lagged behind air temperature, and tracked it loosely. Backwater temperature exceeded 34°C on that transect on 23 July as air temperature exceeded 43°C. During July, midday temperatures between 10 and 40 cm depths varied by as much as 11°C. a decrease of 0.37°C/cm, on the BB transect thalweg. This point was poorly stratified in April and September. Although BB temperatures were 15 to 24°C in June (well above the mainstream temperature of 9-11°C), high winds mixed the backwater and prevented stratification.

Farther riverward and well into the mixing zone, Transect CC 10 cm depth temperature lagged more slowly behind air temperature, and thalweg temperatures were less stratified during mid-summer. The maximum 21-23 July temperature range between 10 and 40 cm depths on the thalweg was less than 5°C. July backwater temperatures on the Transect CC remained well above mainstream river temperatures throughout the day and night. Little thermal stratification was observed there from 17 to 20 September, although backwater temperatures ranged from 13 to 17°C, approximately 5°C warmer than the mainstream.

A preliminary model of backwater temperature at -10 and -40 cm depth revealed that 74% and 78%, respectively of the variance in backwater temperature was explained by immediate and lagged air temperature and wind speed. The points sampled for this model were located approximately 50 m from the mouth of the backwater, and therefore were not directly affected by the river under the <600 m^3/s flows that occurred following the flood in 1996. Spot sample data revealed high levels of spatially discrete thermal stratification, with the head of the backwater responding more strongly to climate and the mouth area responding more strongly to river temperature and flow conditions. A more general model is under preparation to describe climate and discharge influences on backwater thermal stratification.

Aquatic Food Base

Water quality and food availability influence habitat suitability for fish using backwaters. We sampled water quality, as well as plankton and benthos distribution and standing mass before and the Test Flow, and through the 1996 growing season.

DO varied on a diel basis and in relation to temperature and mainstream flow. Substantial variation in DO concentration was observed in the RCC backwater from pre-dawn ("a.m.") to mid-day ("p.m.") in the mid-summer months, with values dropping substantially below that in the mainstream (ca. 10 mg/L) at night and rising to supersaturation (>13 mg/L) during the day. This reflects noctural respiration of the benthos and water column organisms, as well as the daytime production of oxygen by benthic macrophytes.

Two L water samples were collected from discrete, georeferenced transects in the backwater using a hose and pump system, and we filtered 1 L of each 2L sample through pre-weighed Wattman No. 42 filters for plankton standing mass analyses. The remaining 1 L of sample were filtered through Whatmann No. 42 filters, and preserved for plankton composition analyses. Comparable samples were collected in the mainstream. Plankton sampling revealed little AFDM of plankton in the RCC backwater or in the mainstream. June and July plankton AFDM values were <9 mg/L.

We used a petite Ponar dredge (0.023 m^2) to sample ooze and sand-dwelling benthos on numerous transects in the Mile 55.5R backwater. We focused our analyses on three primary aquatic zones: the head (or back) of the backwater which was relatively isolated from the river's influence; the mixing zone from the middle of the RCC to the mouth; and the sand-floored river channel adjacent downstream from the reattachment point. Invertebrates were sorted and preserved in 70% EtOH for taxonomic analyses in the laboratory. Fine sediments were seived through a 1.0 mm mesh filter to collect ooze invertebrates. Volume and area of sediment were measured, and sediment wet mass was measured, with a subsample saved for grain size analyses.

Macrophyte ash-free dry standing biomass (AFDM) at Mile 55.5R was always considerably higher in the RCC mixing zone than in the adjacent sand-floored mainstream. Macrophyte AFDM in the RCC was lowest immediately following the Test Flow, and increased 5-fold to 34 g/m^2 in September, becoming senescent thereafter. Initially, several species colonized the post-flood RCC, including *Chara* sp., *Potomogeton pectinatus* and *Elodea canadensis*. By the end of the growing season, the floor of the RCC at a flow of 250 m^3/s was almost completely covered with a dense bed of *Elodea canadensis*, and the other macrophyte species had largely disappeared. Macrophyte cover returned to near 0 in February 1997 (Stevens, personal communication).

Benthic invertebrate composition and AFDM was strongly altered and reduced by the Test Flow. Benthic composition was strongly dominated by oligochaetes and *Chironomus* sp. midges prior to the Test Flow, with densities in excess of 30,000 organisms/m^2. Also, AFDM was substantially higher in the RCC backwater than in the adjacent sand-floored mainstream. Immediately following the Test Flow, benthic invertebrate AFDM in the head and mixing zones of the RCC had decreased by an order of magnitude and almost no invertebrates were collected in the mainstream. Benthic AFDM increased progressively over the 1996 growing season, with September AFDM approximately 20% of the pre-flood levels. The summer composition included: ostracods > oligochaetes > *Chironomus* sp. midges > *Physella* sp. snails > *Fossaria obrusa* snails > *Pisidium* sp. clams > nematodes.

Predatory aquatic invertebrate species increased in abundance in the water column through the 1996 growing season in the RCC backwater. October 1996 seining revealed hundreds of Corixidae, and numerous Notonectidae and Odonata (mostly Libellulidae). Thus, the potential for predation on small fish increased considerably through the growing season.

Fish Distribution

Fish distribution was monitored using an index of catch-per-unit-effort (CPUE), seasonal seining hauls by AGFD, and by direct observations. Minnow traps were used as a non-sacrificial, non-disruptive means of capturing small fish. Six minnow traps were set in each of three microhabitats: shallow backwater, interaction zone backwater, and mainstream channel margin. Traps were checked at least every 12 hr during each 48 hr sampling period. All fish captured were identified to species, and lengths were measured. We examined each individual for external parasites and injuries, but found none. CPUE was calculated as the number of fish captured/trap/hr set. CPUE provides a relative index of the number of fish in each microhabitat of the backwater between samples and will document fish distribution. CPUE of young fish was

INTRODUCTION

Problem Statement

Colorado River backwaters downstream from Glen Canyon Dam are biologically productive, low velocity, shoreline habitats that warm daily and seasonally, and may serve as important rearing environments for young fish (Holden 1978; Valdez and Clemmer 1982; Carter et al., 1985; Maddux et al., 1987, 1992; U.S. Bureau of Reclamation 1995, including the U.S. Fish and Wildlife Service Biological Opinion; Valdez and Ryel 1995). In Grand Canyon, backwaters typically exist at low discharges when exposed eddy sand bars block recirculating flow. Backwater size and distribution depends on shoreline morphology. The largest and most common type of backwater in Grand Canyon is a return current channel (RCC; Schmidt and Graf 1990; the Type I backwater of McGuinn-Robbins). Recent studies demonstrate that backwater habitats decreased in area and number under Interim Flows (IF) from Glen Canyon Dam in Grand Canyon (McGuinn-Robbins 1995). Reduction in backwater size and number has coincided with a system-wide shift of fine-grained sediment deposits (sand bars) from higher to lower elevations within most eddy depositional settings (Kaplinski et al., 1994, 1995). This shift in stored sediment reflects the reduced sediment supplies since 1963, and the reduced mean annual peak discharge associated with Glen Canyon Dam IF. If native fish use backwaters as intensively in the lower Colorado River basin as in the upper basin, reduction of backwater habitat availability may have a dramatic impact on native fish populations.

The IF regime is similar to the Glen Canyon Dam Environmental Impact Statement (GCD-EIS) Preferred Alternative, and the GCD-EIS recommends coupling an IF-style operating regime with annual to decadal high flows; however, the use of planned flooding for habitat restoration is presently an experimental approach to ecosystem management. A seven-day 1,275 m^3/s release from Glen Canyon Dam was conducted in late March/early April 1996, to achieve sediment redistribution, backwater rejuvenation and reduction of non-native fish populations. On a system-wide basis, the Test Flow increased backwater area by 0.58 ha and 8 new backwaters were formed, a 2.1-fold areal increase and a 1.25-fold increase in backwater number, respectively (B. Ralston, A.T.A., Inc., personal communication). Although planned high flows may rejuvenate backwater habitats, the 1,275 m^3/s flow effects were rather slight and not persistent (B. Ralston, personal communication).

Resolution of GCD-EIS and FWS Biological Opinion issues through adaptive management requires improved understanding of backwater dynamics, particularly by monitoring and analysis of long-term (multi-year) Test Flow effects. However, despite the description of backwater distribution, no integrated analysis of geomorphic, bank and surface water chemistry, thermal stratification, planktonic and fish habitat development has been attempted. In this study we monitored the impacts of the 1996 Test Flow on the physical and biological rejuvenation of selected Colorado River backwaters during the 1996 growing season. We are conducting an integrated *in situ* analysis of backwater geomorphic, geochemical and biological development at River Mile 55.5R, with ancillary measurements at other sites. Backwaters form during high flows and evolve towards wetland or riparian (terrestrial) habitats after large flow events.

The 1996 Test Flow is likely to be the only large flow event in the next few years, and therefore provided a unique opportunity to study this important process in the post-dam Colorado River.

Undisturbed backwater conditions are essential for accurate measurement and modeling purposes, and the Mile 55.5R study site was deemed one of the most appropriate sites at which to conduct these analyses. It was selected because: 1) it contains a large RCC backwater which was likely to exist before and after the Test Flow; 2) it lies upstream from the Little Colorado River, and therefore develops largely in response to dam operations, rather than in response to a combination of mainstream and tributary flows; 3) good historic photographs and bar evolution data are available (Rubin et al. 1990; Stevens et al. 1995); and 4) the site receives little recreational visitation, thereby reducing contamination of the backwater by waste water disposal.

In addition to the Mile 55.5R site, ancillary monitoring of RCC backwaters was conducted at miles -6.5R, 44R and 194L, which are important study sites for sand bar evolution and fisheries studies. The geomorphology and biological attributes of these large sand bars and their associated RCC backwaters have been extensively studied (Valdez et al. 1995), and all sites except 194L lie in Bureau of Reclamation GIS reaches.

Study Objectives

We collected data to test the (null) hypothesis that planned flooding does not result in physical and biological rejuvenation of selected Colorado River backwaters over the subsequent growing seasons sufficiently to improve conditions for young native fish. Our specific objectives include collecting and compiling data on the following issues:

1. Determine the extent of rejuvenation and post-flood alteration of backwater geomorphology.
    - 1a. Determine the extent of physical rejuvenation (enhanced accessible volume related to carrying capacity) of the RCC backwaters.
    - 1b. Determine the extent of scour of fine sediment (silt) from the RCC backwater.
    - 1c. Determine the rate of post-flood aggradation in relation to seasonally-adjusted IF.

2. Determine nutrient storage and mobilization in backwaters during and after the high flow experiment.
    - 2a: Determine sediment geochemistry on the bar and in the RCC backwater.
    - 2b: Determine groundwater and solute flow within the reattachment bar.
    - 2c: Determine groundwater and solute flow from the reattachment bar into the RCC backwater.

3. Determine relationships between climate, flow fluctuations and thermal stability in backwaters.

4. Describe biological development in relation to fish habitat use.
   4a. Determine seasonal plankton distribution, standing mass and production.
   4b. Determine benthic distribution and standing mass.
   4c. Determine fish distribution.
   4d. Determine fish diet.

5. Develop a database that will allow interrelationship of physical backwater development (geomorphic, nutrient flux, climate/river/thermal stability) and biological development (benthos, plankton and fish habitat use).

6. Compile data so that it can be linked to the GCES GIS for predictive purposes in future monitoring and research.

METHODS AND RESULTS

1. GEOMORPHOLOGY

Background

Backwaters in the Colorado River below Glen Canyon Dam are areas with zero to near-zero flow velocities that form on and around sand bars. Sand bars are deposited in eddies defined by channel constrictions (Schmidt and Graf 1990; Schmidt and Rubin 1995; Webb in press), and reattachment bars are the bar type most likely to support RCC backwaters. Typically, eddies with backwaters are also constricted by bedrock or alluvial fans at their downstream ends. The largest backwaters (Type I) typically occur as return-current channels (RCC) on reattachment bars (Melis and Webb 1993; Melis et al., 1994, 1995; McGuinn-Robbins 1995). Reattachment bars are dynamic and their stability varies over relatively short time scales (days to years; Howard and Dolan 1981; Schmidt and Graf 1990; Schmidt 1990, 1993; Clark et al., 1993; Cluer et al., 1993; Kaplinski et al., 1994; Hazel et al., 1993). Therefore, the backwaters they support exhibit considerable temporal variation (McGuinn-Robbins 1995). Type II backwaters are smaller and are often associated with micro-eddies along the margins of sand bars or near other channel irregularities.

Backwaters provide important rearing habitats for native and non-native subadult fishes (U.S. Bureau of Reclamation 1995). Fine, nutrient-rich sediments ($\leq$silt size) typically accumulate in backwaters, which become areas of high productivity and marsh development (Stevens et al. 1995). Owing to their size and relatively stability, RCC backwaters are the most important backwater type as rearing habitats for native fish, because they warm in relation to the cold stenothermic mainstream.

Based on recent field studies and experimental work (Rubin et al., 1990; 1994a; 1994b; Schmidt 1990, 1993) we predict that the second year following the high flow will result in additional aggradation of the RCC through tributary sediment contributions.

Objective 1: Determine the extent of rejuvenation and post-flood alteration of backwater geomorphology.

Sub-Objective 1a: Determine the extent of physical rejuvenation (enhanced accessible volume related to carrying capacity) of the RCC backwaters.

Additional studies of this site are being conducted by other researchers. Historical patterns of bar erosion and aggradation have been determined from analyses of photographs at Mile 55.5R (Rubin et al. 1990, Stevens et al. 1995). Pre- and post-flood geographic information system (GIS) analyses are being undertaken by Utah State University and will be completed in 1997 with logistical support from this project. Scour chains were installed at miles 44L and 55.5R prior to the flow event and were subsequently recovered by J.C. Schmidt (USU, Logan). Excavations of trenches (Appendix 1a) and scour chains, and interpretation of sediment structures, in combination with the topographic measurements, are being used to determine the rates and styles of scour and fill, as well as flow directions. Measurement of daily topographic change during the duration of the flood were undertaken at 44L as part of the USGS sand bar evolution study, and are being reported upon by that research group. Data from daily surveys will provide mean depositional rates on sand bars to help identify the optimum duration and frequency of future planned high flows. Lastly, the miles -6.5R, 55.5R and 194L sites are being mapped to determine the extent of Test Flow impacts on vegetation.

We conducted detailed topographic surveys at Mile 55.5R before and after the experimental flow, and six months after the event, using state-of-the-art surveying techniques for terrestrial and bathymetric topography (Figs. 1a.1-4). The constant 226 m^3/s and 1275 m^3/s flows associated with the Test Flow were used to improve the stage-to-discharge relationship at the Mile 55.5R site (Fig 1a.5). SuperHydro bathymetric surveying techniques were used to map channel-bed topography before and after the Test Flow, and at the six-month post-event interval (Figs. 1a.6-1a.7).

Pre- and post-Test Flow surveys of the channel, eddy and bar surface at Mile 55.5R in March and April 1996, respectively, revealed that 54,829 m^3 of sediment was removed from the channel (constriction to base of the Mile 55.5R bar at stages <226 m^3/s); 13,962 m^3 were removed from the eddy (coupled with a 1,744 m^2 eddy area increase) below that same stage; and the bar aggraded 4,684 m^3 above that stage (with a concomitant decrease in area of 1,846 m^2; Figs. 1a.3-4 and 1a.6-13). These data demonstrate that no more than 4,684 m^3 of sediment (6.8%) of the total 68,791 m^3 of sediment moved during the Test Flow contributed to bar building. Much of the aggrading sediment may have been derived from upstream sources, not the local eddy complex, thus much less than 6.8% of the sediment may be used in local bar building. These findings are relevant to managers concerned with flood frequency planning.

The Mile 55.5R bar sustained significant degradation and reshaping during the late summer. The reattachment ramp that developed during the Test Flow lay downstream of the normal summer flows. The foot of this large body of sand was exposed to downstream flow and eventually (possibly catastrophically, cf Cluer 1992) failed. A new reattachment ramp associated with the filling eddy developed and was observed as early as July. The September bathymetric survey shows a slump feature near the Test Flow reattachment point, demonstrating that some of the sand deposited there during the Test Flow remained (Fig. 1a.9). Thus, bar topography has continued to change in response to flows.

Hyposmetric-style analyses of the Mile 55.5R RCC backwater volume in relation to the stage-to-discharge relationship revealed the following relationship:

$$V_{Backwater} = 18.144-(1191.633*Q_{Mainstream})$$

$$(R^2 = 0.988, F_{1,4} = 421.056, p < 0.0001)$$

where $V_{Backwater}$ is the total volume of the backwater between discharges of 100 and 700 m^3/s (the range of interim flows), and $Q_{Mainstream}$ is river discharge. At flows above 700 m^3/s the bar surface begins to be inundated, and backwater stage-to-volume relationship becomes horizontal. There hypsometric analyses revealed that backwater volume decreased by at least 20% as a result of the Test Flow.

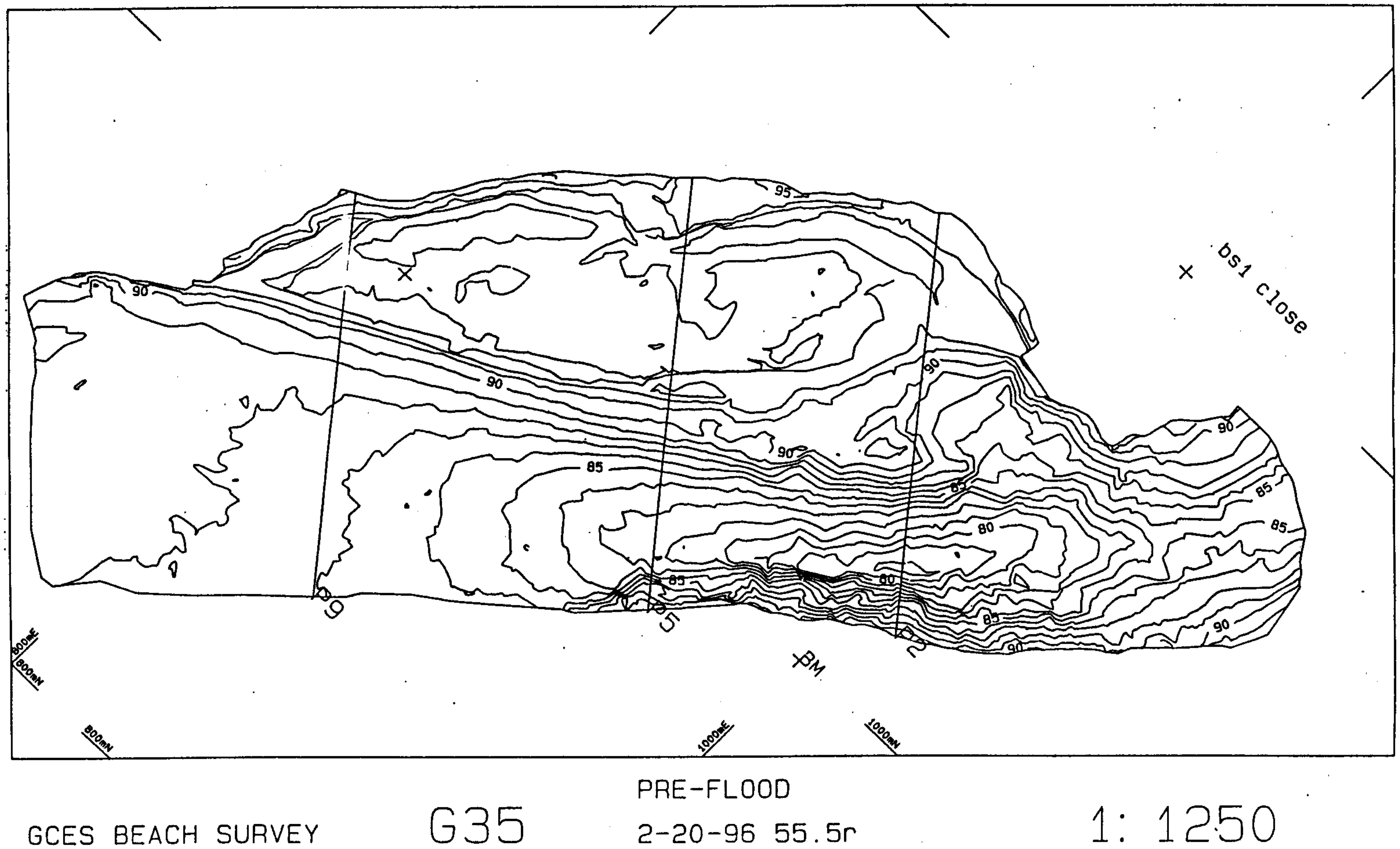


Figure 1a.1: Pre-flood Mile 55.5R channel, eddy and bar surface topography.

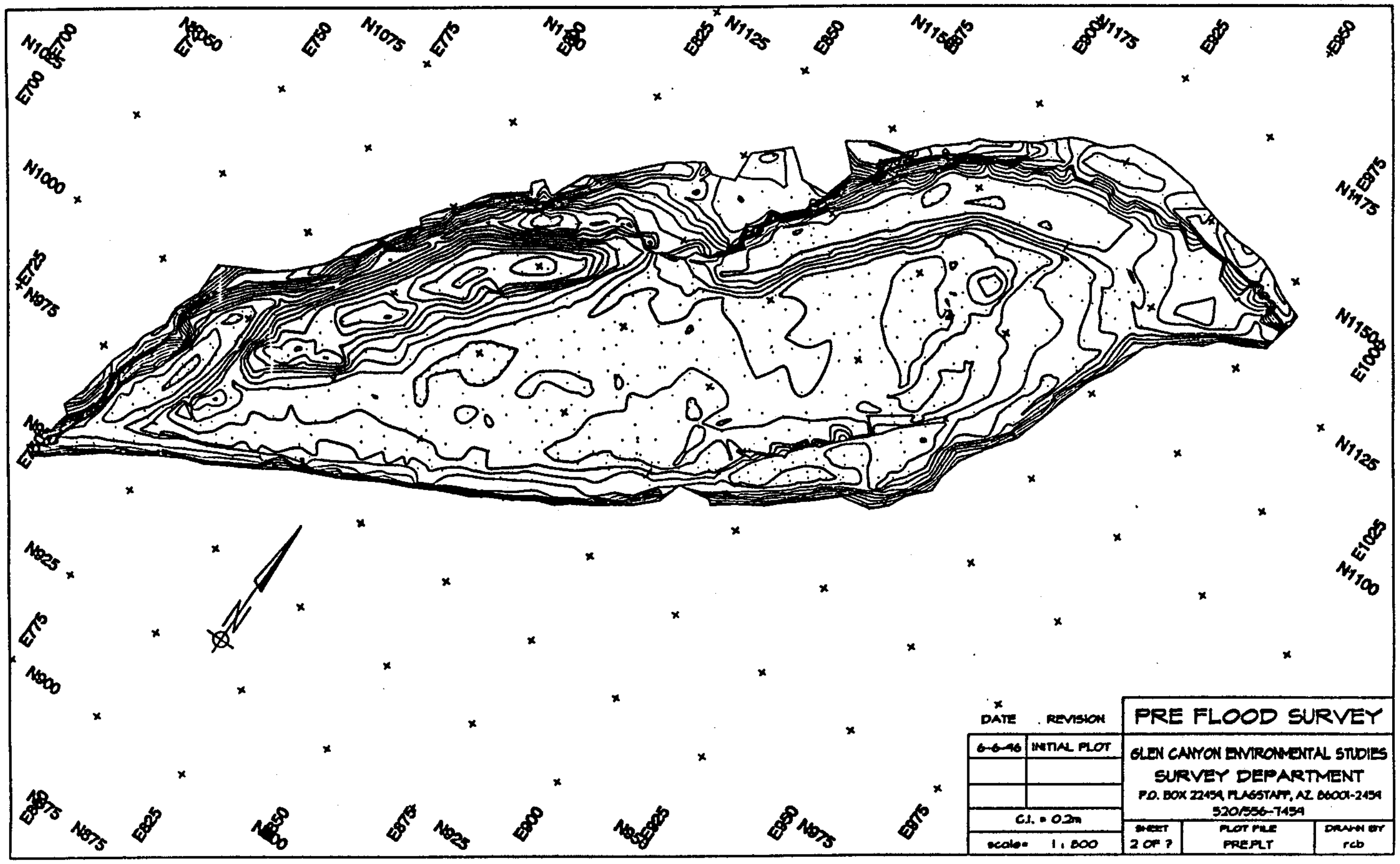


Figure 1a.2: Pre-flood Mile 55.5R bar surface topography.

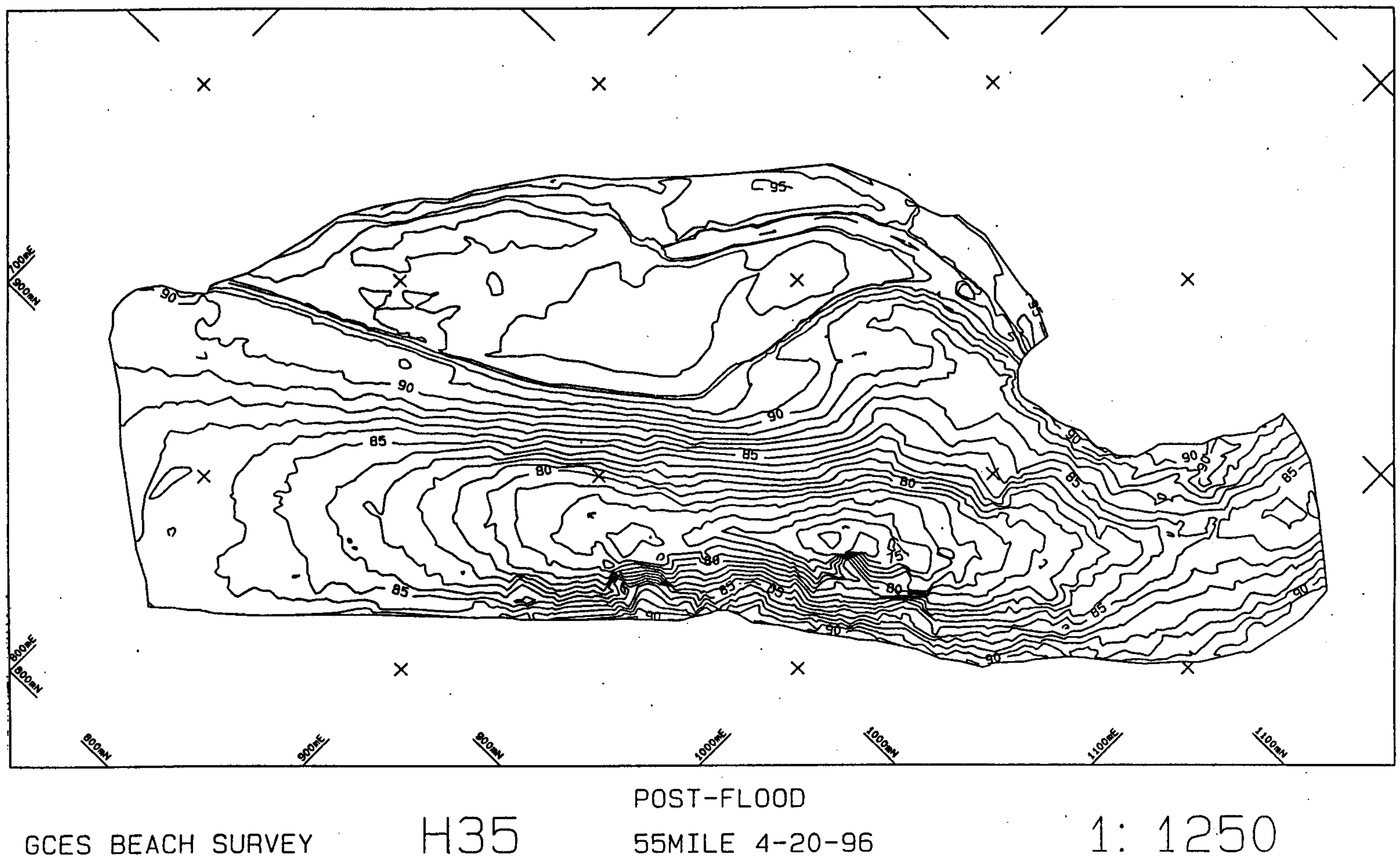


Figure 1a.3: Post-flood Mile 55.5R channel, eddy and bar surface topography.

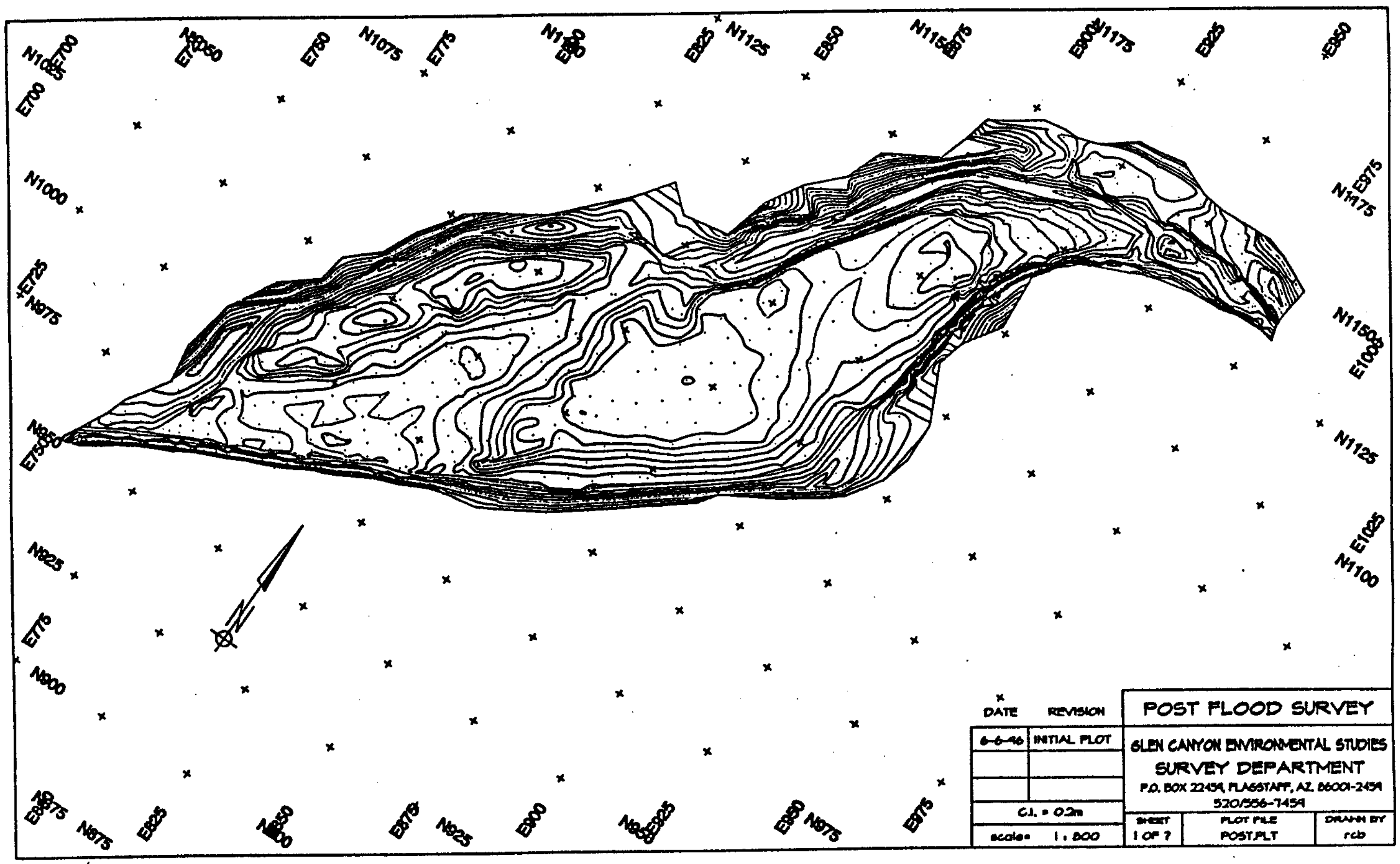


Figure 1a.4: Post-flood Mile 55.5R bar surface topography.

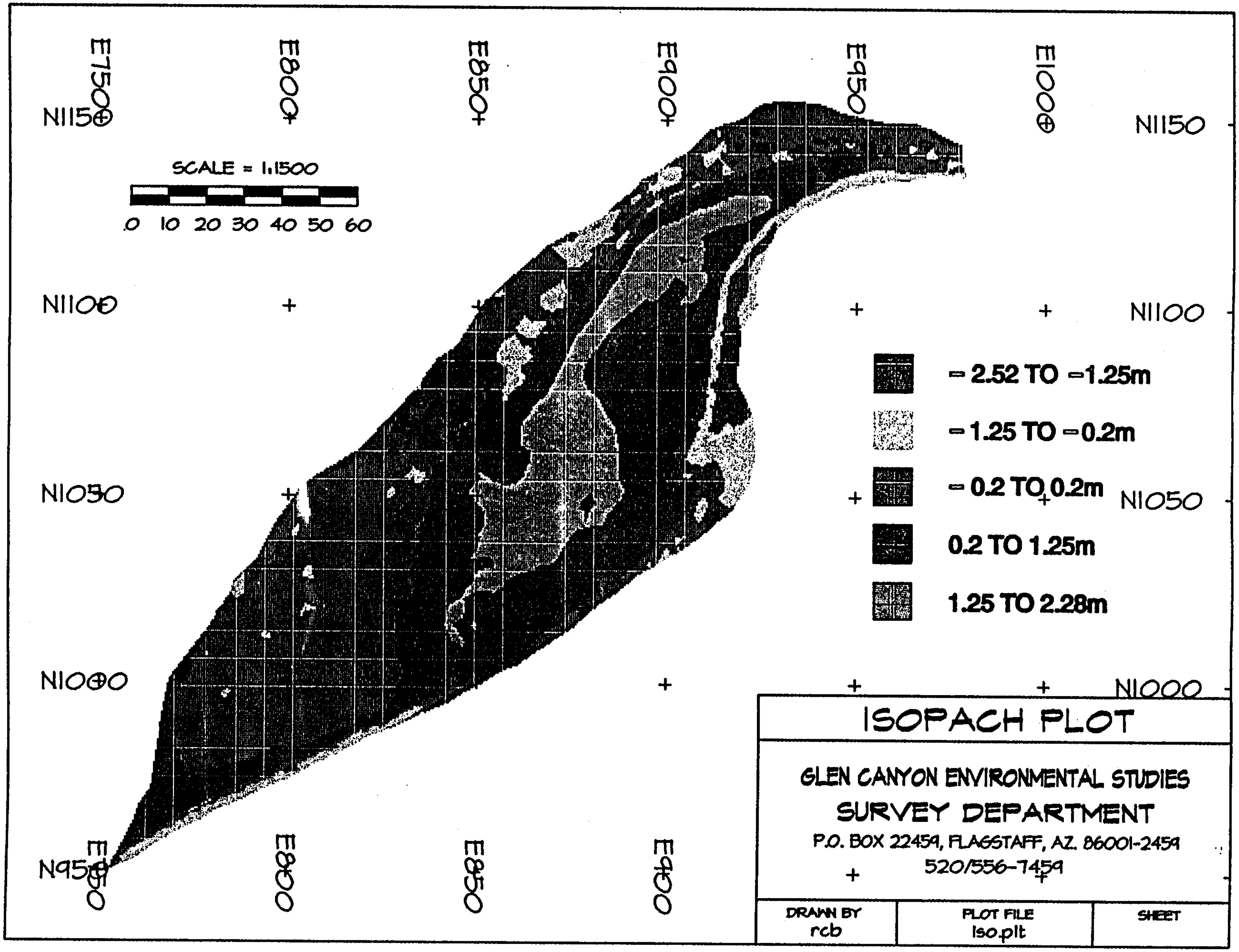


Figure 1a.5: Pre-flood versus post-flood topographic differences at Mile 55.5R.

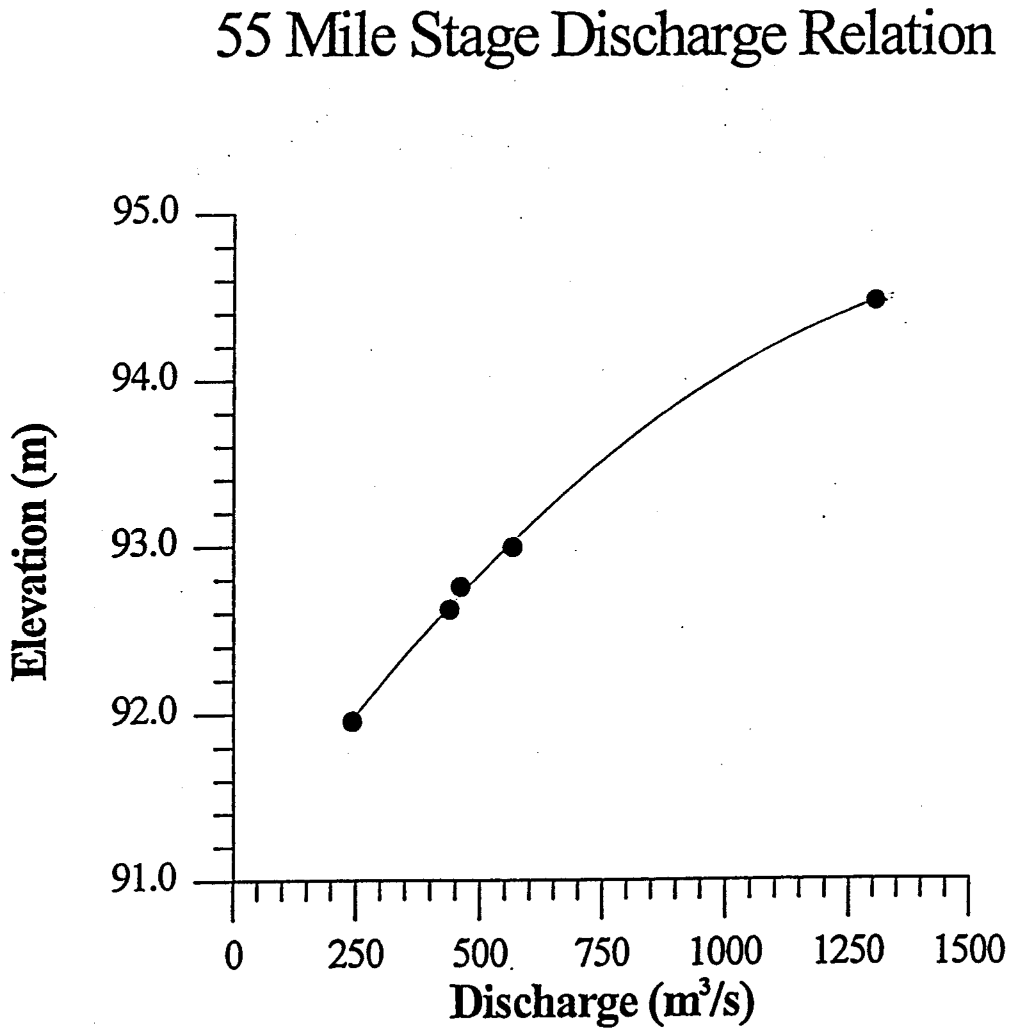


Figure 1a.6: Stage discharge relationship based on measured 221m^3/s and 1275 m^3/s discharges at Mile 55.5R.

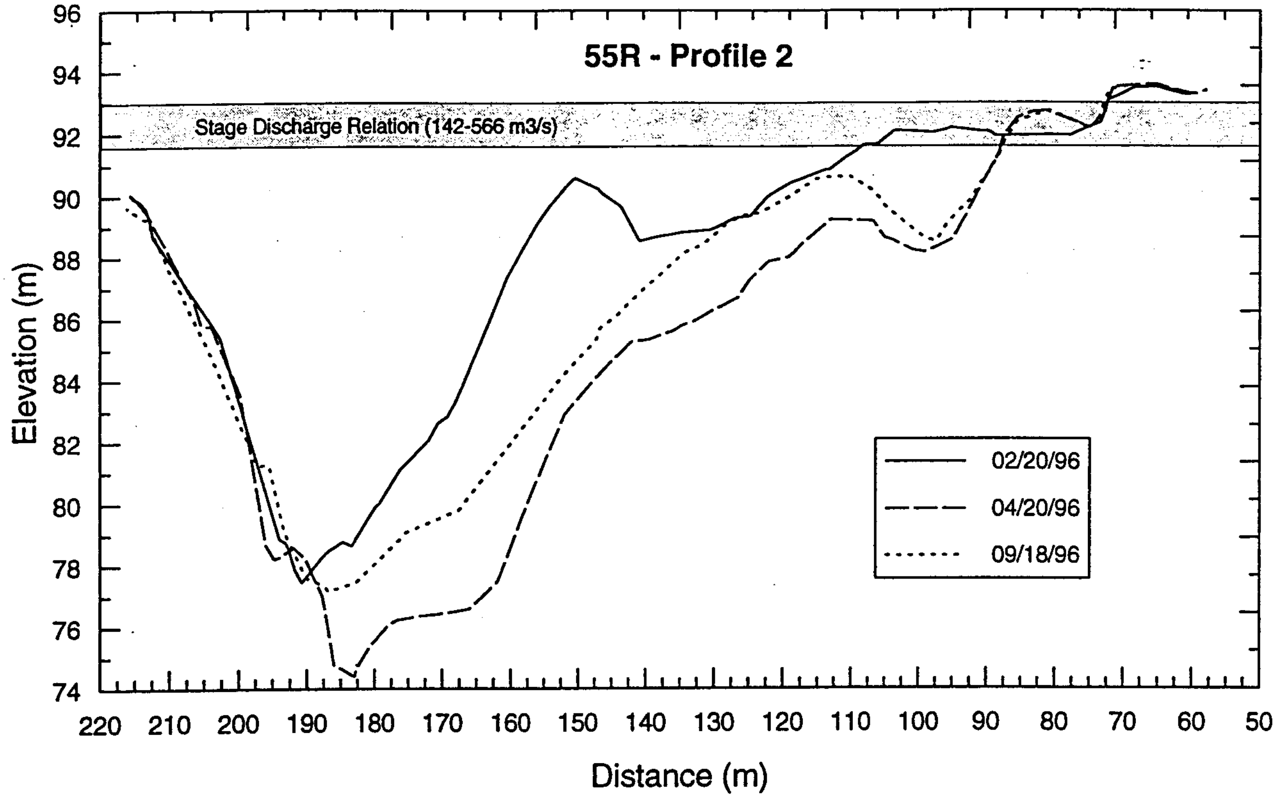


Figure 1a.7: Pre-flood, post-flood, 6 month post-flood Profile 2 changes at Mile 55.5R.

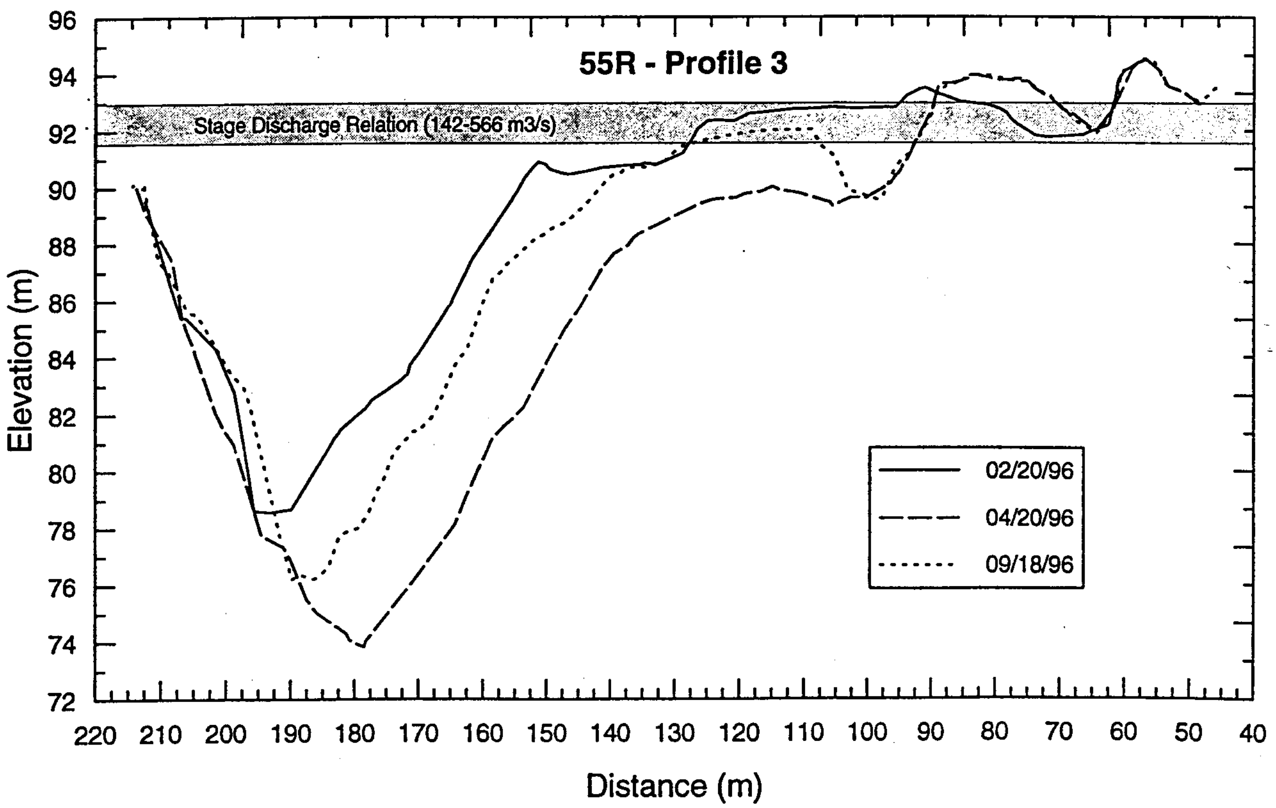


Figure 1a.8: Pre-flood versus post-flood Profile 3 changes at Mile 55.5R.

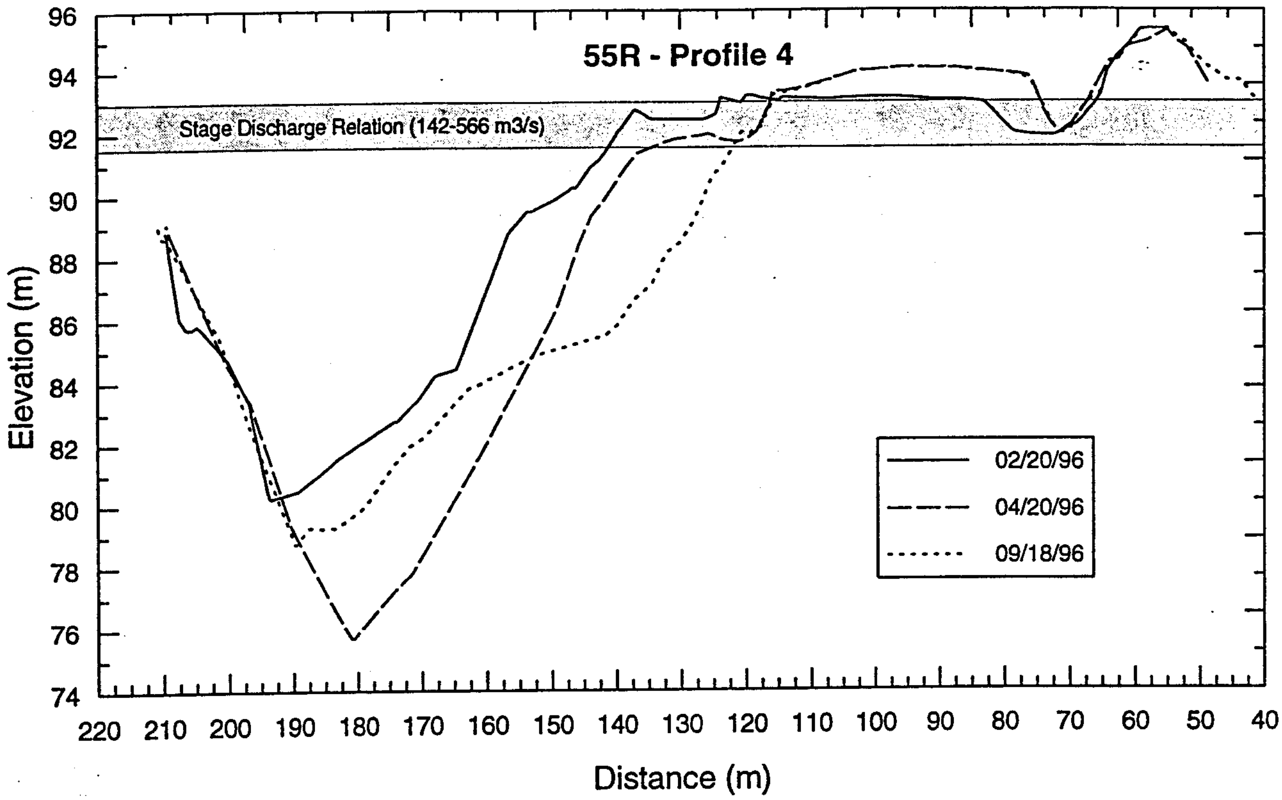


Figure 1a.9: Pre-flood versus post-flood Profile 4 changes at Mile 55.5R.

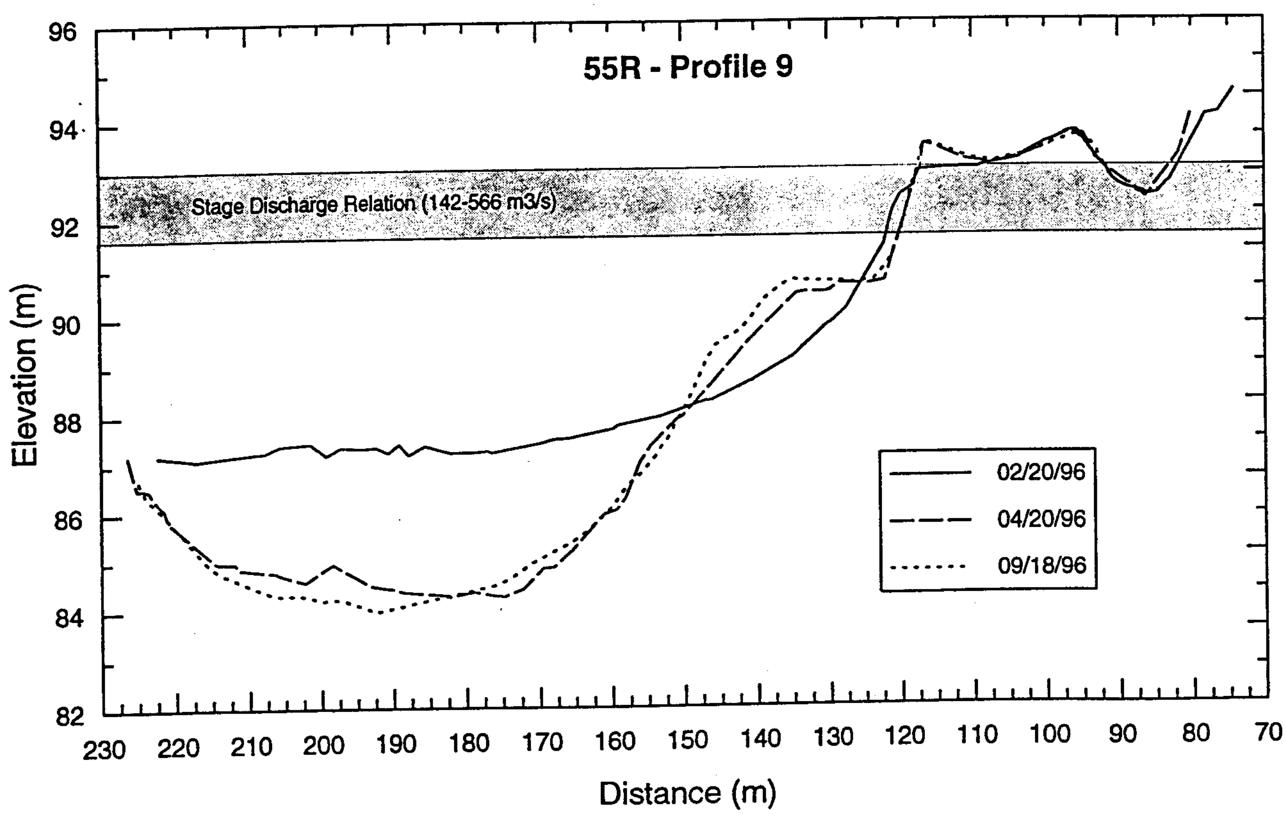


Figure 1a.10: Pre-flood versus post-flood Profile 9 changes at Mile 55.5R.

Sub-Objective 1b: Determine the extent of scour of fine sediment (silt) from the RCC backwater.

Grain size samples were collected at each site before and after the high flow experiment to determine the extent of scouring of the backwaters. The above surveys and trenching efforts were used to determine the extent to which fine sediment was scoured from the RCC backwaters during the Test Flow. The Mile 44L RCC was considerably altered by the flood, while the Mile 55.5R backwater was narrowed but was not scoured, and the Mile 194L backwater was relatively unaffected by the event.

The Mile 55.5R RCC backwater decreased in surface area by approximately half, but remained about equally deep (Figs. 1a.4, 1a.9-10, 1b.1-2). Therefore, the Test Flow reduced backwater volume and did not rejuvenate backwater geomorphology at this site. We attribute the lack of change at this site to the thick deposit of silty fine sand on the floor of the RCC, material which is not readily erodible under the <0.9 m/s velocities sustained by the RCC during the Test Flow.

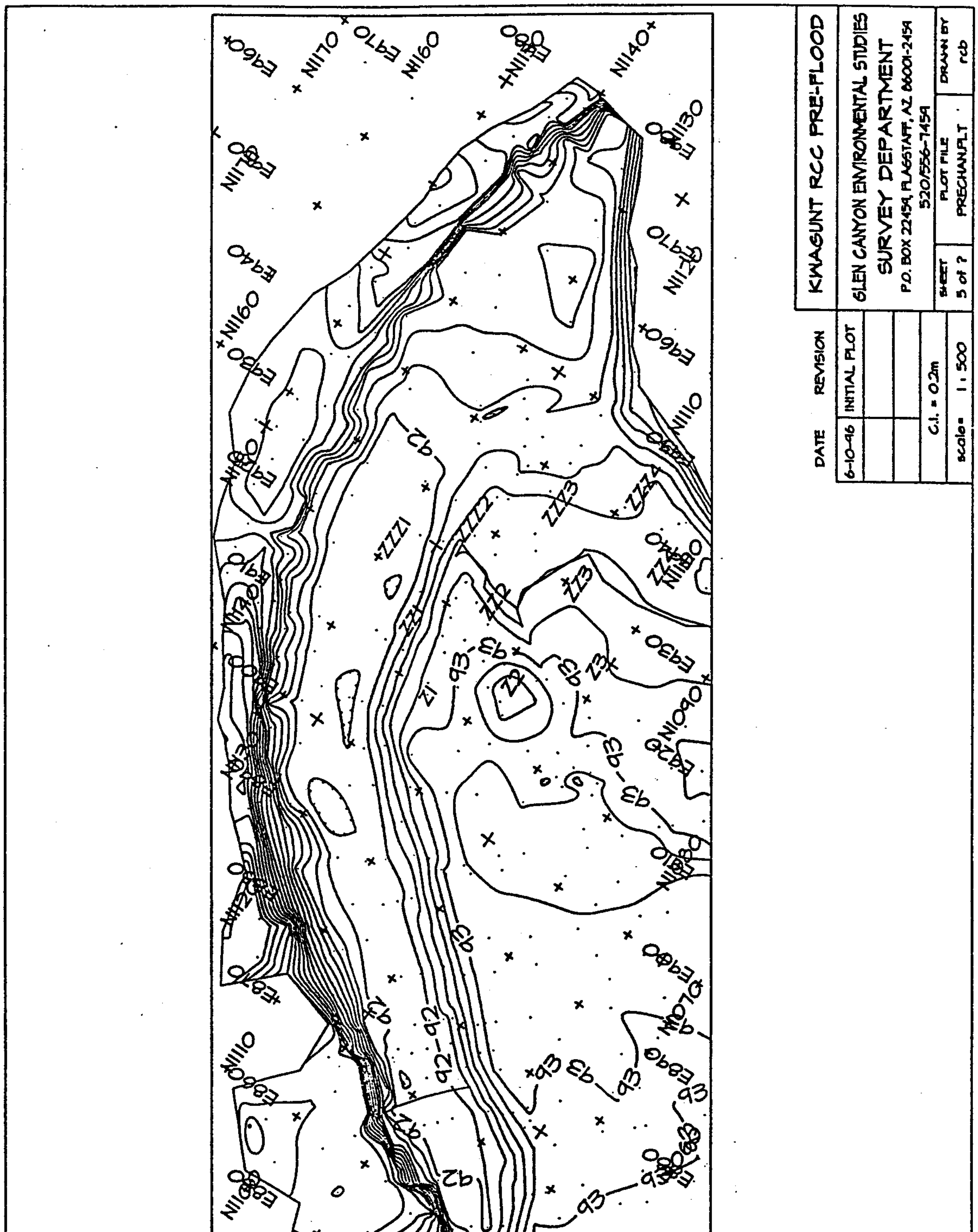


Figure 1b.1: Pre-flood backwater topography and bathymetry at 55.5R.

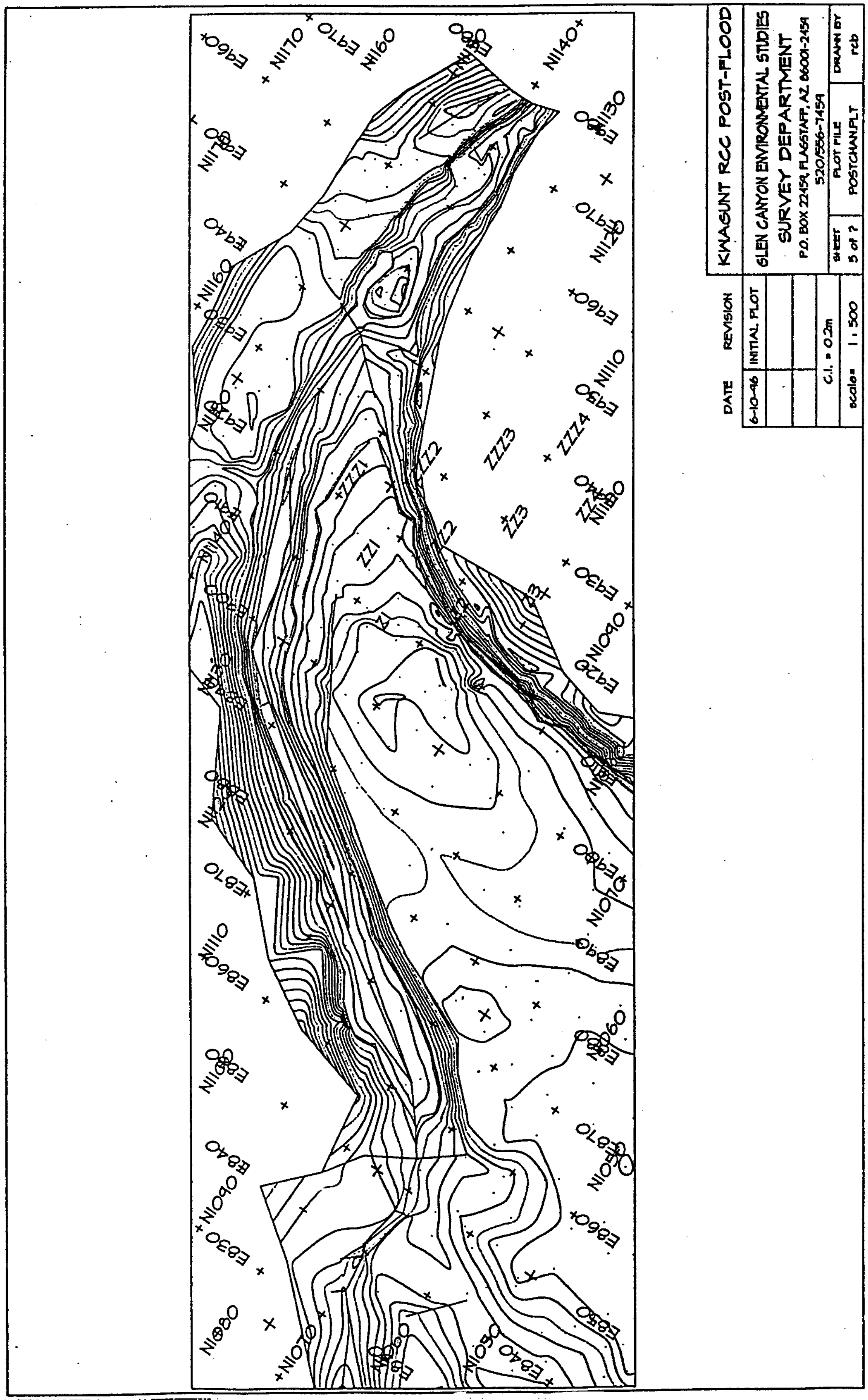


Figure 1b.2: Post-flood backwater topography and bathymetry at 55.5R.

Sub-Objective 1c: Determine rates of post-flood aggradation in relation to seasonal Interim Flows.

Following the return to seasonally-adjusted interim flows in late spring 1996, and based on the above survey data, we expected fine sediment accumulation to occur in RCC's, in combination with erosion of elevated sand deposits to lower elevations. These processes reduce the depth and area of the backwaters over time. We predicted that backwater infilling would begin after the experimental flow, and continue through summer high fluctuating flows, with punctuated infilling occurring during high (sediment-laden) tributary discharges over a period of several years. These predictions were partially borne out at Mile 55.5R, largely because of aeolian saltation of sand from the bar surface into the RCC backwater; however, the rate of bank collapse into the backwater has been low, and post-flood RCC morphology appears to have been relatively stable. Without occasional flood disturbance, we expect that RCC-controlled backwaters will eventually aggrade, turning into marsh habitats and then into sandbar habitats.

Objective 1: Conclusions

In summary, the 1996 data demonstrate that geomorphic rejuvenation of the Mile 55.5R backwater did not occur through the 1996 Test Flow. Although surface flow velocities reached ca. 0.9 m/s and were sufficient to deposit up to 1.8 m of new sand, these velocities were insufficient to scour the compacted silt floor of the RCC, preventing major restructuring of the RCC bed. Deposition of new sand reduced maximum RCC volume by at least 20%, and produced a narrower but not deeper backwater. Low tributary inflows during 1996 limited aggradation of the RCC, therefore hyposmetric relationshiops established during the Test Flow have remained essentially unchanged.

2. GEOCHEMISTRY

Background

Biogeochemical and hydrologic processes affect backwater development by controlling nutrient and sediment delivery, and quantifying water flowpaths is critical to modeling nutrient flux throughout the bar. Parnell et al. (1995) monitored biogeochemical conditions of several reattachment sand bars to model hydrogeologic influences on nutrient transport. They reported that RCC backwaters serve as nutrient sinks during IF and buried organic deposits exert a large influence on groundwater nutrient dynamics. Nitrogen leaves RCCs by gaseous export through decomposition, ammonification and denitrification, while RCCs sequester phosphorus through adsorption on fine sediments (Fig. 2.1). Although these processes have been identified, a quantitative model of bar hydrology is needed to quantify nutrient flux. The experimental discharge buried a great deal of marsh and other vegetation, further altering nutrient and organic carbon processes from the natural condition. Living and buried vegetation can play a major role in nitrogen transformation (Fig. 2.2) that has not occurred in this river system to as large an extent before. Monitoring provides insight into multi-year nutrient mobilization/immobilization.

Mainstream flow and the geochemistry of reattachment bar ground water affect surface water biogeochemistry in backwaters through several processes: (1) the burial, mineralization and discharge of organic matter in the alluvium; (2) the hydrogeologic transport of nutrients; (3) adsorption and desorption of nitrogen and phosphorous phases; and (4) oxidation/reduction reactions involving phase transformations of nitrogen species. The first process occurred both during bar deposition (Boyle and Watson 1991) and during the Test Flow, which was of sufficient magnitude to inundate the bar (Parnell et al., 1995). Much marsh vegetation, which has been increasing in RCCs since GCD closure, was buried under fine grained sediments during natural 1993 Little Colorado River floods, as well as during the Test Flow. Thus the organic content of downstream RCC soils has increased as a result of flooding. The fine-grained sediments in RCCs act as low conductance streams between the RCC and the reattachment bar aquifer (Petroutson et al., pers. commun.) .

Hydrogeologic characterization of reattachment bar groundwater has indicated changing hydraulic gradients with varying river stage (Budhu et al. 1992; Carpenter et al., 1995a,b; Cluer 1992). Changes in the physical characteristics of eddies as a result of the high flow discharge affect ground-water flow paths between the reattachment-bar ground water and surface water in the river. Furthermore, we demonstrated that a flushing, bar-topping discharge event induces maximum nutrient flux. Changes in the flow system thus affect cycling of nutrients between the RCC and the river.

The adsorption/desorption and redox processes by which nutrients are mobilized in reattachment-bar waters is well understood (Parnell et al., 1995), and the processes by which nutrients move through the reattachment bar ground water can be interpreted through the application of groundwater and particle tracking models (Anderson and Woessner, 1992). However, the migration of nutrients in riparian systems may be attenuated by reduction in the frequency and magnitude of river discharge. We correctly predicted that the post Test Flow discharge regime reinitiated the process of RCC aggradation, potentially contributing phosphorous-rich sediments. The rate of return to pre-flood biogeochemical conditions is being controlled by the amount and nutrient content of organic matter and is influenced by the rate of mineralization of newly buried organic matter.Objective 2: Monitor and model nutrient storage and mobilization in the Mile 55.5R backwater during and after the high flow experiment.

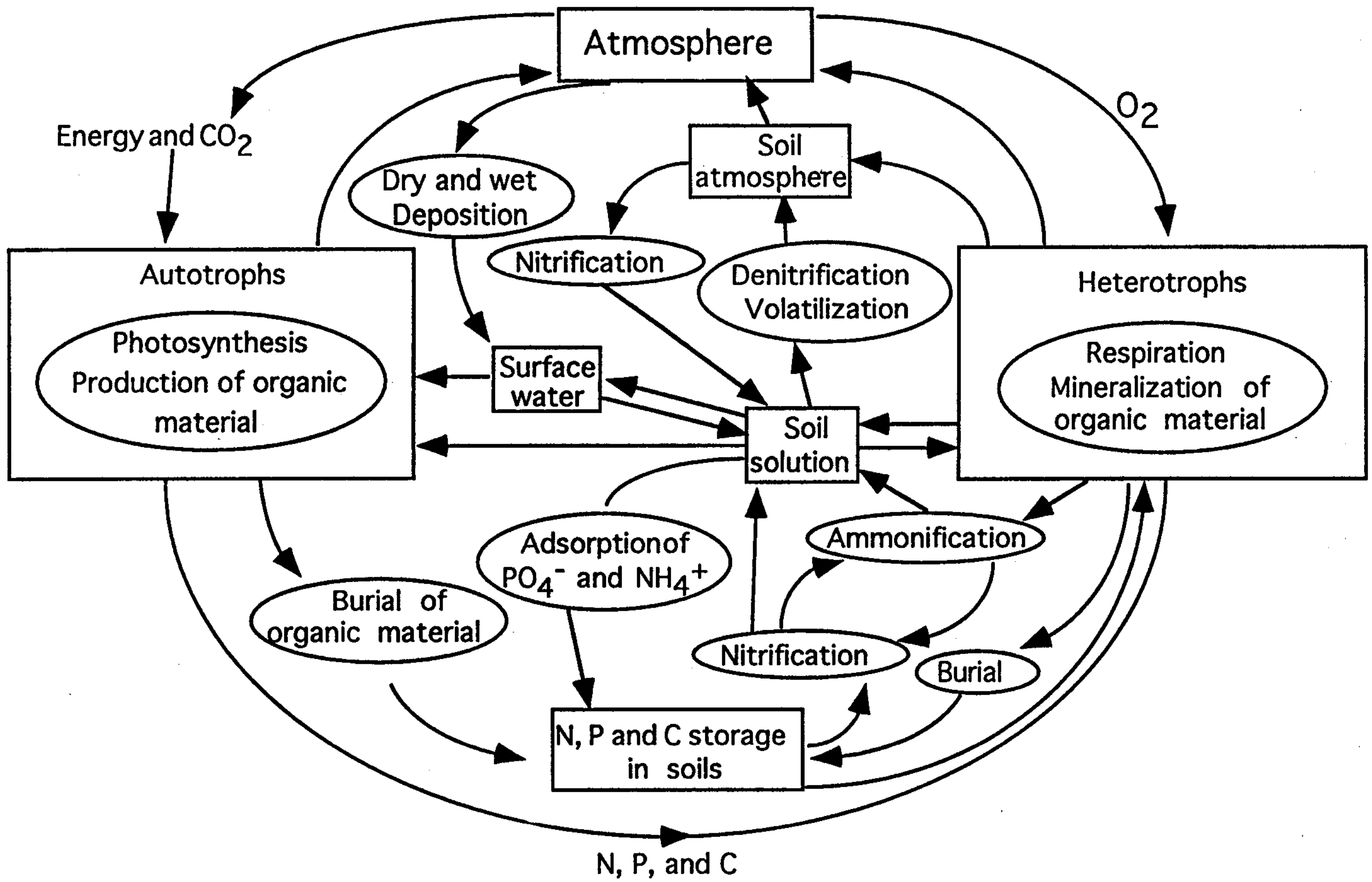


Figure 2.1. Biogeochemical processes and storage sites (pools) in riparian ecosystems. Ellipses represent processes and boxes represent pools.

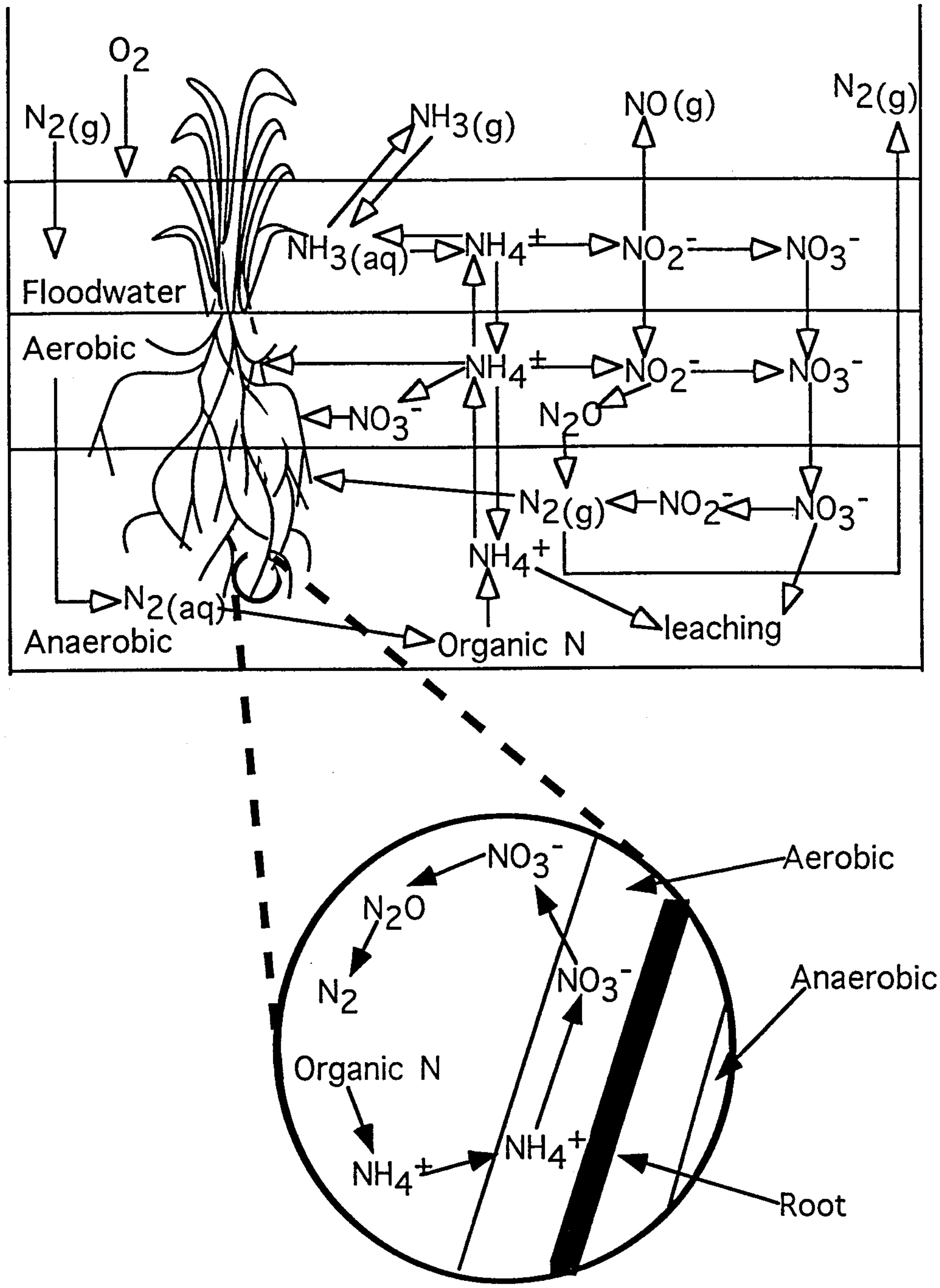


Figure 2.2. Flowpaths of nitrogen transformations in wetland soil-plant water systems. Modified from Reddy, 1976.

OBJECTIVE 2: Determine nutrient storage and mobilization in backwaters during and after the high flow experiment.

Sub-Objective 2a: Determine sediment geochemistry on the bar and in the RCC backwater.

Methods

We used the Glen Canyon Dam controlled release to test the hypothesis that flooding results in the biogeochemical rejuvenation of Colorado River ecosystems through the burial and accelerated decomposition of organic material. We sited 44 wells (1.5, 3 and 6 m deep) at beaches with return current channels (RCC) at miles -6.5R, 55.5R, and 194L, using the techniques of Carpenter et al. (1995a) and Parnell et al. (1995).

Surface water samples were collected from the mainstream and the RCC backwater during each run. Sampling occurred before the Test Flow, on the falling limb of the hydrograph, during the 226 m^3/s post-flood constant flow. Post-flood diel sampling occurred at the end of spring during low flow month Interim Flows, near the end of the higher stage summer fluctuating flows and in late October or early November (low flows). Pre-flood samples were taken at miles -6.5R (3/23/96, 45L (3/3/96), 55.5R (3/12/96) and 65R (3/14/96). Post-flood samples were taken at miles -6.5R (4/27/96), 55R (4/2/96,4/3/96,4/5/96,4/6/96,4/7/96,6/18/96, and 10/29/96), and 194L (6/26/96 and 11/08/96).

We sampled ground and surface waters immediately before, immediately after, one month after, two months, and six months after the event. The Carbon Creek site failed to redevelop an RCC backwater, therefore we abandonned it as a study site. Field analyses included pH, specific conductance , temperature, nitrate, nitrite, ammonium, and dissolved oxygen (DO). Laboratory analysis of collected samples included and non-purgeable organic carbon (NPOC) and orthophosphate. Data are included in Appendix 2a.1.

Results and Discussion

The Test Flow buried living and detrital organic material under 0.2 to 1.8 m of sand at the test beaches. We did not find any evidence of scour in the RCC at any site. Casual observation of RCC's other than our sites made directly after the recession further supported this observation. Established RCC's lost depth, width and length. New RCCs that developed behind new reattachment bars were ephemeral and were already eroding by 1 day after the conclusion of the 226 m^3/s constant flow. The smallest depths of burial occurred at Mile -6.5R and the greatest depths of burial were observed at Mile 194L.

Groundwater in all beaches decreased in concentrations of NPOC after the flood ranging from 85-278% (average from all beaches = 4.95+/-1.72 mg/L before; 22.5+/-21.4 mg/L after). NPOC concentrations at Mile -6.5R increased from 3.95 (+/- 1.7) to 7.32 (+/-10.5, Fig. 2a.1) and had not recovered by 228 days after recession (Appendix 2a.1; Parnell et al. 1996). NPOC concentrations at Mile 55.5R increased gradually during recession and had doubled (to 22.5 mg/L) by June of 1996 (Fig. 2a.2). Ammonium in groundwater samples increases ranged from 79 to 617% (average from all beaches: 0.80+/-1.21 mg/L before:

5.82+/- 2.67 mg/L after). At Mile -6.5R, ammonium continued to increase through the summer of 1996 (Fig. 2a.1). Previous work at Mile -6.5R documented slightly decreased ammonium concentration between spring and summer (Parnell et al. 1996). Ammonium increases at Mile 55.5R began with the recession of the Test Flow and continued through the summer. Ammonium levels were still elevated in the fall of 1996. Although ammmonium concentrations varied spatially, increases in individual wells .were significant. Significant decreases in DO concentrations in groundwaters occurred at two sandbars, miles -6.5R and 55.5R (Figs. 2a.1, 2a.2). Increased in ammonium and NPOC and decreases in DO are consistent with increasing rates of microbial respiration within the beaches.

Average orthophosphate concentrations decreased at Mile -6.5R after the Test Flow, and then increased in the fall of 1996 at several. Orthophosphate concentrations decreased at Mile 55.5R after the Test Flow and remained low through summer and fall.

Surface water in RCC's had highly variable NPOC concentrations. Averages for samples taken at miles -6.5R and 55.5R increased through the fall of 1996 (Fig. 6***). Nitrate concentrations in the RCC increased through the summer and decreased through the fall. Increases in ground water NPOC were reflected in RCC increases which in turn is reflected in increases in mainstem waters.

Mainstream surface water nutrient concentrations did not appear to have been substantially influenced by the Test Flow. Because ammonium converts to oxidized species in the presence of atmospheric oxygen, the large concentrations of ammonium in groundwater are not reflected in surface waters. Dissolved inorganic nitrogen in surface waters is predominantly nitrate and nitrite. Nitrate increases in mainstream water were minimal and were not noticeably different than seasonal values in previous years without flooding impacts (Bennett et al., 1995).

Mainstream surface water orthophosphate concentrations did not appear to have been altered by the Test Flow (Fig. 2a.3). Orthophosphate concentrations in the Glen Canyon reach and at 55.5R were not impacted by the flood or by the low flows of November 1996 (Figs. 2a.4, 2a.5). In contrast, changes in mainstream surface water NPOC concentrations can be attributed to seasonal conditions and conditions of flow from Glen Canyon Dam. In particular, mainstream NPOC increased significantly between summer and fall at miles -6.5R and 55.5R (Figs. 2a.3, 2a.5). Prolonged low flows in November 1996 influenced groundwater flux into the mainstream (Fig. 2a.3). Because groundwater flow rates seldom exceed 0.5 m/d, low flows over the course of several weeks are required to change groundwater flow patterns and increase groundwater flux into the mainstem. Even though NPOC concentrations in the Glen Canyon reach were the lowest of the three sampling events, concentrations increased downstream to higher levels than occurred during the previous sampling trips. NPOC is likely being delivered to the mainstream by groundwater draining from alluvial deposits.

Figure 2a.1. $[NH_4^+]$ and [NPOC] increase and [DO] decrease in ground waters after flooding at -6R. Orthophosphate concentrations do not significantly change.

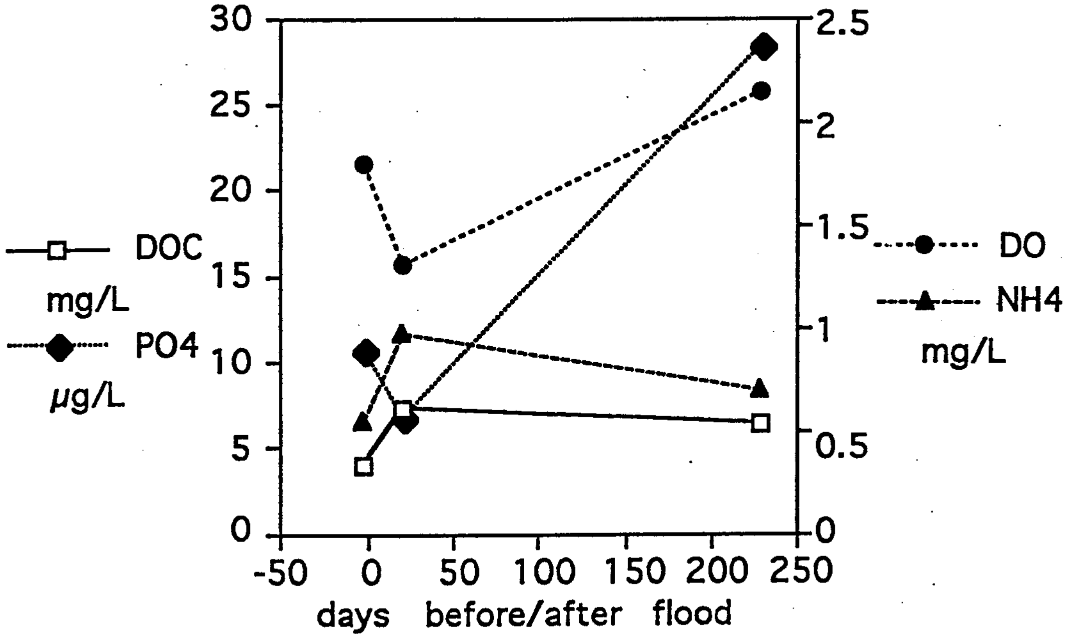


Figure 2a.2. $[NH_4^+]$, [NPOC] increase and [DO] and orthophosphate decreases in ground water after flood at 55R

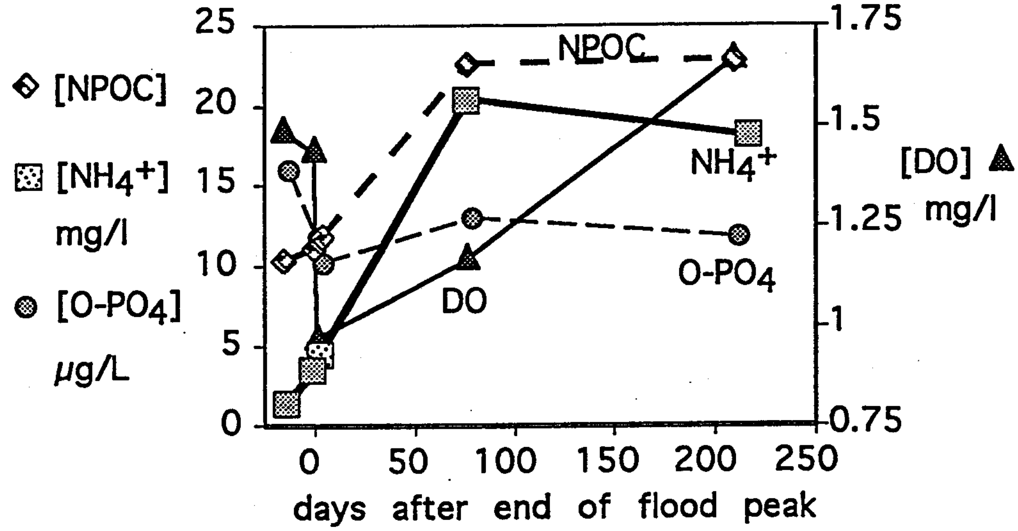


Figure 2a.3. NPOC concentrations in the Glen Canyon reach of the Colorado River change with different flow regimes after the flood event.

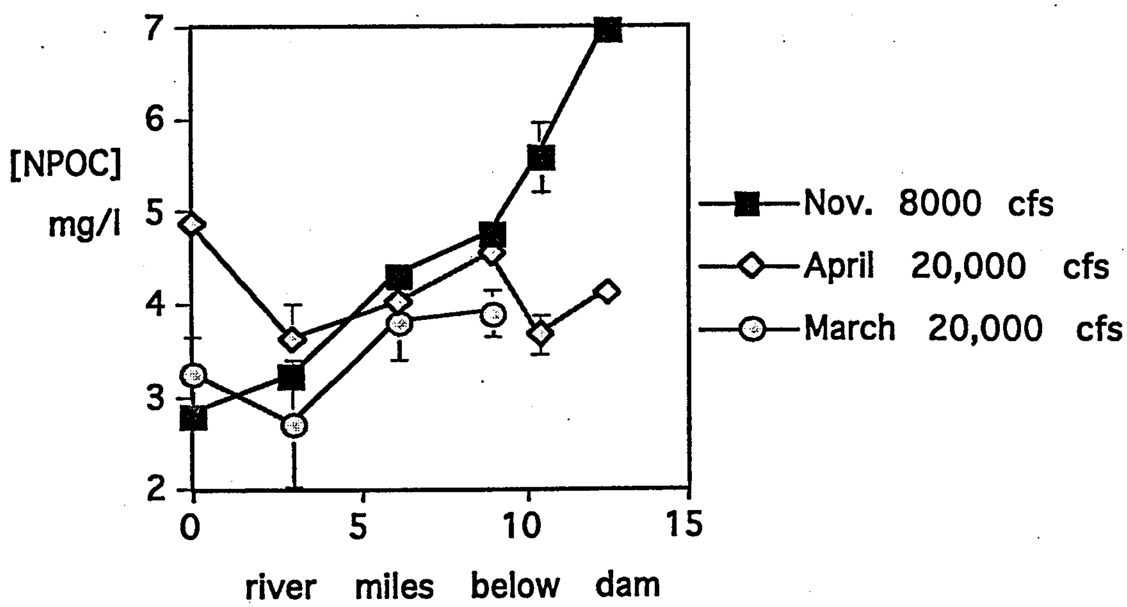


Figure 2a.4. Orthophosphate concentrtations in the Glen Canyon reach by different flow regimes after the flood event.

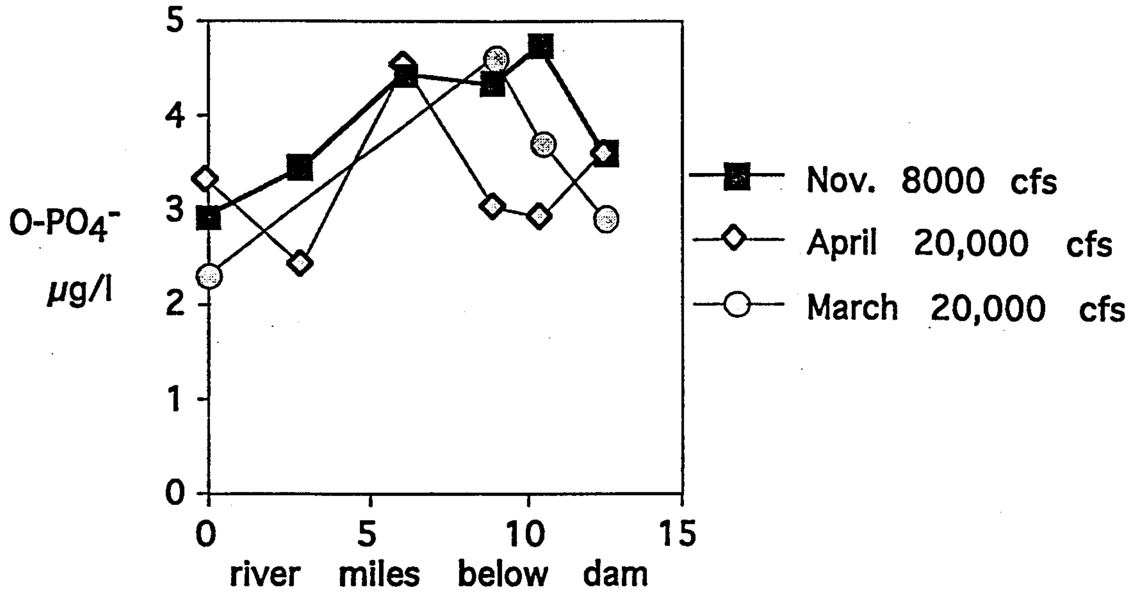


Figure 2a.5. Seasonal increase in mainstem dissolved C, N, and P at 55R

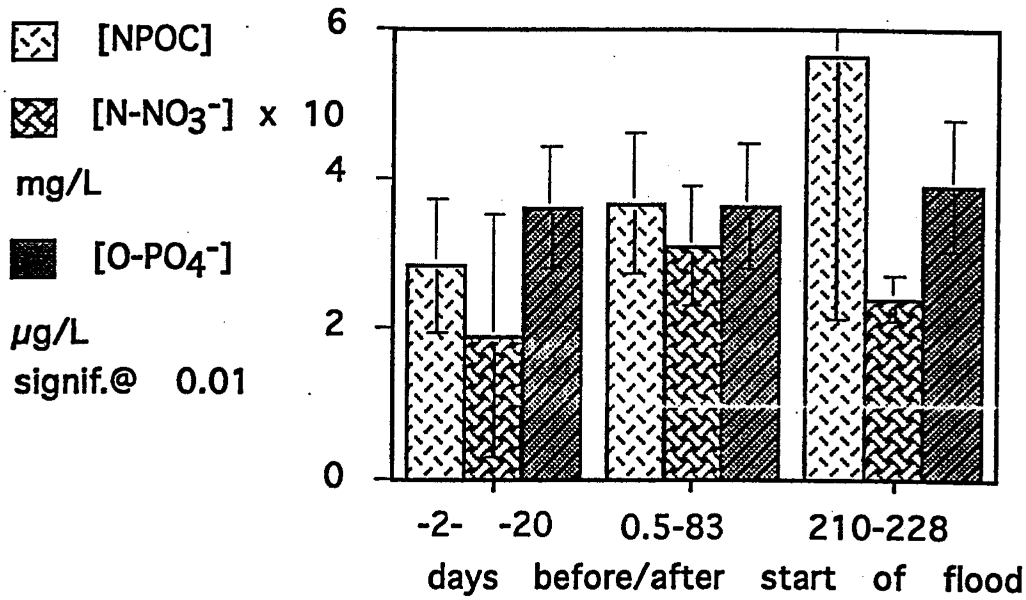
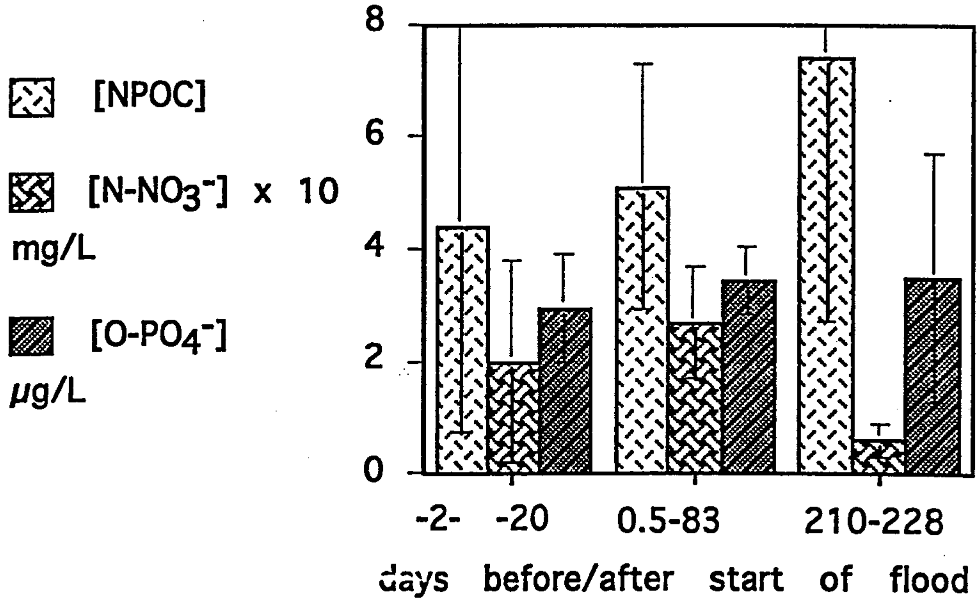


Figure 2a.6. Seasonal increase in return current channel surface water dissolved C, N, and P after flood



Sub-Objective 2b: Determine groundwater and solute flow within the reattachment bar.

Methods

In 1996 we installed permanent and portable wells at the Mile 55.5R study site during four visits in a transect across the bar and a transect along the return current channel, using the techniques of Carpenter et al. (1995a) and Parnell et al. (1995) (Appendix 2b.1). During the first visit from 6 to 24 March we installed eight drive-point wells, four temporary river stage gages, two in the main stream and two in the backwater, and we developed four PVC, jetted wells. During the second visit from April 1 to April 15 we installed four temporary river stage gages, two in the main stream and two in the backwater, and nine drive-point wells. We redeveloped two of the PVC, jetted wells after two PVC wells had been lost in the flood. We installed one new temporary river stage gage during the third visit from June 12 to June 27 and used three existing river stage gages, one in the main stream and two in the backwater. Two new drive-point wells were installed while nine existing drive-point wells and two existing PVC, jetted wells were used. During the fourth visit from October 24 to October 30, two new temporary river stage gages were installed, one in the main stream and one in the backwater, with locations surveyed for each. River stage gages installed during previous trips were not present. The fourth trip utilized nine existing drive-point wells and two existing PVC, jetted wells.

We measured water levels and river stages and conducted slug tests during each of the four trips. Water levels and river stages were measured during the first visit at each well and river stage gage during two daily stage fluctuations from March 11 at 11:00 to March 13 at 15:00. Slug tests were conducted (at a minimum) in triplicate for each well for a total of 68 tests during the first visit. During the second visit, water levels and river stages were measured at each well and river stage gage from April 3 at 19:00 to April 7 at 12:00. Measurements were taken from the beginning of the falling limb of the flood to 8,000 cfs discharge. Slug tests were conducted in permeable materials (at a minimum) in triplicate for each well for a total of 33 tests for the second visit. Water levels were collected for each well from June 17 at 10:00 to June 20 at 9:00 during the third visit. Measurements were taken from the beginning of the falling limb of the flood to 8,000 cfs discharge. River stage data was collected for each river stage gage from June 17 at 10:00 to June 20 at 9:00 over two and a half river stage fluctuations. Slug tests were performed in permeable materials at a minimum of five replicates for each well for a total of 110 test during the third visit. Water levels were measured for each well during the fourth visit on Saturday, October 26 and Tuesday, October 29 over one daily stage fluctuation each day. River stage measurements were taken for each river stage gage on Saturday, October 26 and Tuesday, October 29 over daily river stage fluctuations. Slug tests were conducted in permeable materials at a minimum of three replicates for each well for a total of 38 tests during the fourth trip.

Mean hydraulic conductivity was calculated for pneumatic slug tests using the Bouwer and Rice method for data collected during each visit. Time-dependent hydraulic conductivity measurements were made. Hydrographs were constructed from data collected at each visit for each well and river stage gage. We analyzed water-table depths for selected stage conditions from each visit. Hydrogeologic profiles were constructed for selected stages and water levels from each visit.

Surface water samples were collected from the main current and the RCC backwater during each run. Sampling was conducted in the post-flood spring period, and seasonally thereafter on three field excursions. Sampling was conducted on the falling limb of the hydrograph and during the April 1996 post-flood constant 226 m^3/s flow (three sets of samples). Post-flood diel sampling was conducted in June and October.

Results and Discussion

This hydrogeologic research demonstrated variability in hydraulic conductivity in a large reattachment bar induced by the 1996 Test Flow (Appendix 2b.2; Springer et al. 1996). Hydraulic conductivity at a well in the middle of the reattachment bar was 40% less after the flood as compared to the pre-flood condition. Up to 1.8 m of new sediment was deposited on the reattachment bar during the flood compressing the sediments and lowering the hydraulic conductivities. Two months after the flood, when discharges from Glen Canyon Dam were returned to Interim Flows, hydraulic-conductivity values were 20% less than the pre-flood condition after sediment had been removed from the sandbar by hydraulic and aeolian erosion.

Sub-Objective 2c: Determine ground-water and solute flow from the bar into the backwater.

Methods and Results

We collected sufficient data to prepare a preliminary model of the directions and magnitudes of groundwater and solute flow through the reattachment bars, scheduled for preparation in 1997. As described on our FY97 proposal, we are in the process of constructing conceptual groundwater and solute flow models incorporating hydraulic conductivities obtained from slug tests for the wells at the instrumented beaches, sediment characterization data obtained from soil cores, stage data, synoptic-water levels obtained from the wells, and in situ streambed conductance. The conceptual model compartmentalizes the geologic information into hydrostratigraphic units and the boundary conditions necessary for simulation with numerical techniques. Ground-water flow and advective solute transport are being evaluated using a three-dimensional finite difference numerical flow model, MODFLOW (McDonald and Harbaugh, 1988), coupled with a particle tracking code, MODPATH (Pollock 1989). Necessary field data also include information on the water balance for each river reach and topographical surveys of each beach. The conceptual model is being incorporated into the model design and executed. The model is being calibrated to hydraulic heads and river stages measured in wells and at stage gages in the instrumented beaches.

In FY97 we will incorporate rates of the reactive species into the simulation models. The purpose for this will be to simulate how different release scenarios from Glen Canyon Dam will influence mobilization and transport of nutrients through reattachment bars.

3. CLIMATE AND BACKWATER WARMING

Background

Microclimatic fluxes significantly affect flora and fauna through exchange of heat, moisture and momentum with the climate system. Temperature and production relationships have been studied by Owens and Crumpton (1995) in an upper Mississippi River backwater; however, in Grand Canyon backwater thermal data have only been collected sporadically, with little attention paid to warming mechanisms. Thermal stratification of initially cold, shallow stillwater habitats is limited by five overall factors (Oke 1987): 1) penetration of energy through the water column, permitting diffusion throughout the water body; 2) convective and advective processes within the water permitting heat redistribution; 3) evaporation at the surface, allowing for cooling which destabilizes the upper stratum and allows mixing (these processes are likewise influenced by wind speed); 4) the high thermal capacity of water (three times more heat is required to increase the temperature of water as compared to an equal volume of soil); and 5) the duration of stable conditions which permit thermal stratification to occur between destabilizing events.

Radiative energy absorption by water can be partitioned into several energy fluxes (Sellers 1965; Rosenberg et al. 1983; Geiger et al. 1995):

$$Q^* = Q_H + Q_E + Q_G + dQ_S + net Q_D$$

where Q^* = net all-wave radiation, Q_H = turbulent heat flux of sensible heat, Q_E = latent heat of evaporation, Q_G = ground heat flux, dQ_S = change of heat storage in the layer, and $netQ_D$ = net horizontal heat transfer due to water currents or advection within the air (Olyphant and Isard 1988).

Four radiative exchanges comprise the net all-wave radiation which is generally considered to be the fundamental controlling flux in the total surface energy balance allowing for the additional fluxes to occur (Brazel and Marcus 1987). Net radiation is comprised of both shortwave (solar) and longwave (terrestrial) radiation, and is conventionally expressed:

$$Q^* = (K_{in} - K_{out}) + (L_{in} - L_{out})$$

where K_{in}, K_{out}, L_{in}, and L_{out} are incoming and reflected shortwave and longwave radiation, respectively. Incoming solar radiation is:

$$K_{in\ o} = S_o + D_o$$

where the direct beam (S) and diffuse radiation (D) carry subscripts ($_o$) representing horizontal, unobstructed irradiances. The incoming shortwave component of the radiation balance is most important since all other fluxes depend on it for their energy inputs (Garnier and Ohmura 1968).

Ground heat flux is a fundamental portion of the energy balance and will be considered in detail in this project. All resulting fluxes are positive when directed toward the water and negative when directed away. These energy fluxes are dependent on air and water temperature, atmospheric moisture, stability conditions, size and depth of the water body, and degree of cloud cover (which influences the availability of energy brought to the surface). Under cloudy conditions net radiation values will diminish, significantly reducing energy available for exchange at the surface. Therefore, the water heat storage change can be calculated from measured temperature profile changes over time, provided conditions are stable. The primary energy sink by day is Q_S (Oke 1987), since most of the incoming shortwave radiation is primarily absorbed by the water. The daily stored energy becomes the source of energy at night, sustaining an upward flow of heat to the atmosphere.

The thermal stability of Colorado River backwaters is strongly influenced by climate variables as well as by unsteady flows in the cold-stenothermic mainstream. We used 1996 climate data from the Mile 55.5R bar to develop a point-specific model that relates climate variables to water temperature. This model reasonably accurately predicts backwater temperature given climate and mainstream discharge. A more generalized model will be developed in the next phase of this research.

Objective 3: Determine relationships between climate, flow fluctuations and thermal stability in backwaters.

Methods

A georeferenced network of water and air thermistors, and a soil heat flux plate were established to study heating of the backwater at Mile 55.5R. Thermistors were positioned along four transects spanning the backwater, with measurements of water temperature at -10 cm and at -40 cm, as well as air temperature +20 cm at the backwater thalweg. Water temperatures were measured at 15 minute intervals and recorded on a CR10 data logger, which was downloaded during each visit.

A temporary climate station was established at the midpoint of the Mile 55.5R backwater, and recorded air temperature, radiant energy, and wind speed. Precipitation at the site was insignificant during our visits there. The transect associated with the climate station was used to develop the point-specific warming model.

Water temperature and Hydrolab™ variables were spot-sampled at surveyed locations throughout the backwater at thermally critical intervals through the day and night: dawn, sunrise (on the backwater), noon, immediately prior to backwater sunset, immediately after sunset, dusk, and one to two times during the night.

Climate data were described in relation to thermal stratification patterns. Pending additional funding, these relationships were related to unsteady mainstream flows by analysis of those transects that bridge the backwater/mainstream boundary. Data from thermistors is being compiled and the April and June data are presented in Appendix 3a.

Mainstream flow data were incorporated into the point-specific model. Flow at the Mile 55.5R site was determined by comparing the hydrograph there with that at the USGS Little Colorado River gauging station, 9 km downstream (Fig. 3.1). A 0.5 hr interval was apparent between these two sites across the range of interim flows observed at the site during the 1996 growing season.

We conducted stepwise multiple regressions to evaluate the effects of 17 climate and physical variables on backwater temperatures at -10 cm depth at the thalweg on the midpoint of the backwater: immediate temperature and temperature lagged at 30 minute intervals for 3 hr over the backwater and over the bar surface, wind speed (m/s), soil heatflux (W/m^2), relative humidity, net radiation, and mainstream discharge (m^3/s). The same variables were used to correlate backwater temperature at -40 cm depth. All temperatures were measured in °C.

Results and Discussion

Climate data reflect diel radiation inputs, moderated by cloud cover and wind during the different seasonal visits (Fig. 3.2-3.5). In general, relative humidity was negatively correlated with air temperature and wind velocity ("RH-207", "T-207", and "Wind-Sp", respectively, in Fig. 3.3), and we recorded cross-channel wind gusts in excess of 20 m/s during the June sampling period. September wind speed were low, rarely exceeding 3 m/s (Fig. 3.4). In turn, these variables influenced net radiation (Figs. 3.2 and 3.5; Appendix 3a).

The relationship between backwater and air temperature varied as a function of proximity to the river. The AA transect near the head of the backwater was shallow, and generally tracked air temperature closely (Fig. 3.6). The backwater head was often dewatered and we did not focus attention on thermal modeling there.

The BB transect lay riverward of Transect AA, and had a deeper channel. Consequently water temperature there lagged behind air temperature, and tracked it loosely (Fig. 3.7-3.11). Backwater temperature exceeded 34°C on that transect on 23 July as air temperature exceeded 43°C (Fig. 3.7). During July, midday temperatures between 10 and 40 cm depths varied by as much as 11°C. a decrease of 0.37°C/cm, on the BB transect thalweg. This point was poorly stratified in April and September (Figs. 3.7, 3.10, and 3.11, respectively). Although BB temperatures were 15 to 24°C in June (well above the mainstream temperature of 9-11°C), high winds mixed the backwater and prevented stratification (Fig. 3.8)

Farther riverward and well into the mixing zone, Transect CC 10 cm depth temperature lagged more slowly behind air temperature, and thalweg temperatures were less stratified during mid-summer. The maximum 21-23 July temperature range between 10 and 40 cm depths on the thalweg ("CC2(-10)" and "CC2(-40)", respectively in Fig. 3.12) was less than 5°C. July backwater temperatures on the Transect CC remained well above mainstream river temperatures throughout the day and night. Little thermal stratification was observed there from 17 to 20 September, although backwater temperatures ranged from 13 to 17°C, approximately 5°C warmer than the mainstream (Fig. 3.13).

Transect DD lay across the mouth of the RCC backwater, and reflected strong influences of the mainstream river during the nighttime hours, and warm draining backwater during the afternoon and evening hours (Fig. 3.14). Temperature spikes on 20 and 22 June reflect exposure of the sensors to ambient air temperature during low flows (Fig. 3.9).

Backwater spot temperature at 10 cm depth varied considerably over 1996 growing season (Fig. 3.15). Backwater temperature always exceeded that of the river in mid-summer under the <570 m^3/s flows we observed, but temperatures occasionally fell below that of the river in spring and fall (and commonly did so in winter, Stevens personal communication). In general, the head of the backwater sustained higher temperatures than did the mixing zone. A similar pattern was observed at the bottom of the RCC thalweg (Fig. 3.16).

We used the climate tower data to predict backwater temperature on Transect CC. The following relationships between climate and backwater thermal development were obtained at -10 and -40 depths on this transect at approximately the middle of the backwater:

$$T_{-10} = 4.944 - .187T_{Air20,Lag90} - .343T_{Air20,Lag180} + .338T_{Air200} + .180T_{Air100,Lag90} + .483_{Air100,Lag180} + .118U_{200} - .005Q^*$$

($R^2 = 0.736$, $F_{11,400} = 144.531$, $p < 0.0001$ all individual factors $p < 0.05$)

and

$$T_{-40} = 4.517 - .120T_{Air20,Lag60} - .143T_{Air20,Lag90} - .328T_{Air20,Lag180} + .370T_{Air200} + .093T_{Air100,Lag60} + .129T_{Air100,Lag90} + .462T_{Air100,Lag180} + .148U_{200} - .004Q^*$$

($R^2 = 0.772$, $F_{11,400} = 144.531$, $p < 0.0001$ all individual factors $p < 0.05$)

where T_{-10} and T_{-40} are backwater temperatures at -10 cm and -40 cm depths, respectively, at the RCC thalweg at the middle of the backwater; $T_{Air20,Lag60}$, $T_{Air20,Lag90}$ and $T_{Air20,Lag180}$ are air temperatures 20 cm above the thalweg midpoint, lagged by 60, 90 and 180 minutes, respectively; T_{Air200} is air temperature 200 cm above the upstream midpoint of the bar; $T_{Air100,Lag60}$, $T_{Air100,Lag90}$ and $T_{Air100,Lag180}$ are air temperatures 100 cm above the upper bar surface lagged by 60, 90 and 180 minutes, respectively; U_{200} is wind speed (m/s) 200 cm above the upstream bar midpoint; and Q^* is net radiation.

These results indicate that air temperature over the backwater and on the bar surface, coupled with wind speed and net radiation, are good predictors of individual points in the backwater. Interestingly, mainstream discharge did not play a significant role in these relationships. This may be attributed to the position of the point selected for modeling here, which lies 50 m from the mouth of the RCC and therefore is somewhat buffered from direct river impacts. The range of flows (225 to 500 m^3/s) encountered during the study is not sufficiently large to inundate the bar and flush the backwater. Additional model validation and application of these results to the entire backwater are proposed in 1997.

Error in the present models are attributable to unmeasured variables, additional lagged air temperature effects, and to distinctive the micro-environmental "seiches" that mix the Mile 55.5R backwater when it is fully connected to the mainstream. Under high, relatively constant flows, water and suspended materials flux at a rate of 1.5 m/min or more in response to stage changes of up to 5 cm/cycle. We presume these low frequency, mainstream-generated waves are the result of vortex shedding onto the shoreline. We are continuing to analyze the frequency of these waves and their variability at different sites, in an effort to relate them to discharge.

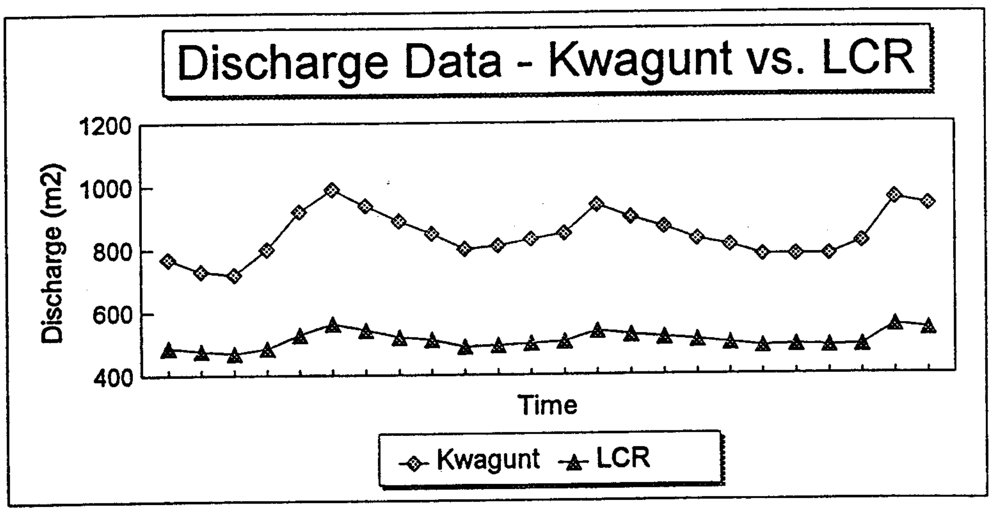


Fig 3.1: Correlation between instantaneous stage at Mile 55.5R and the Above Little Colorado River mainstream flow gauge.

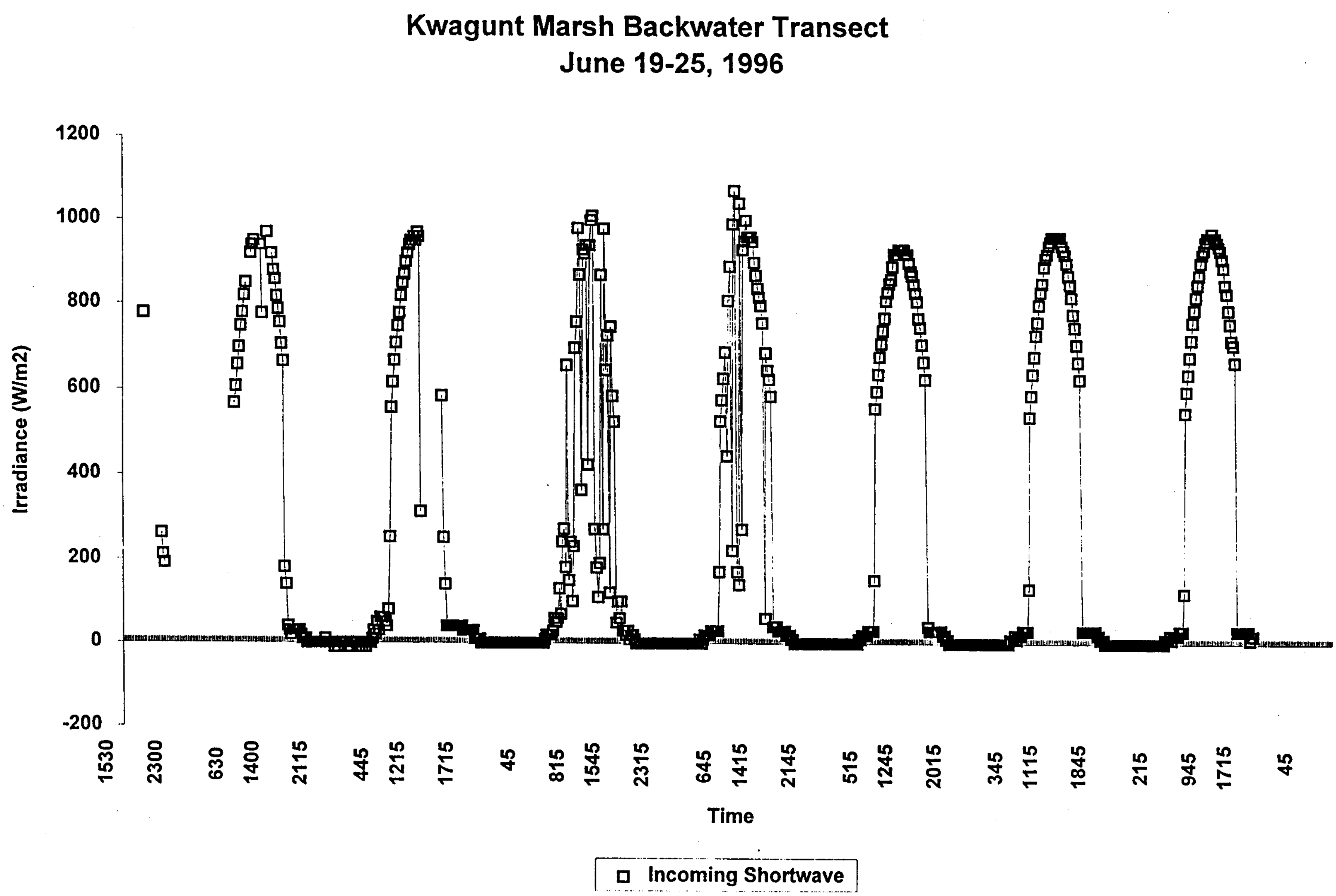


Fig 3.2: An example of diel patterns of incoming shortwave radiation at Mile 55.5R, 19-25 June 1996.

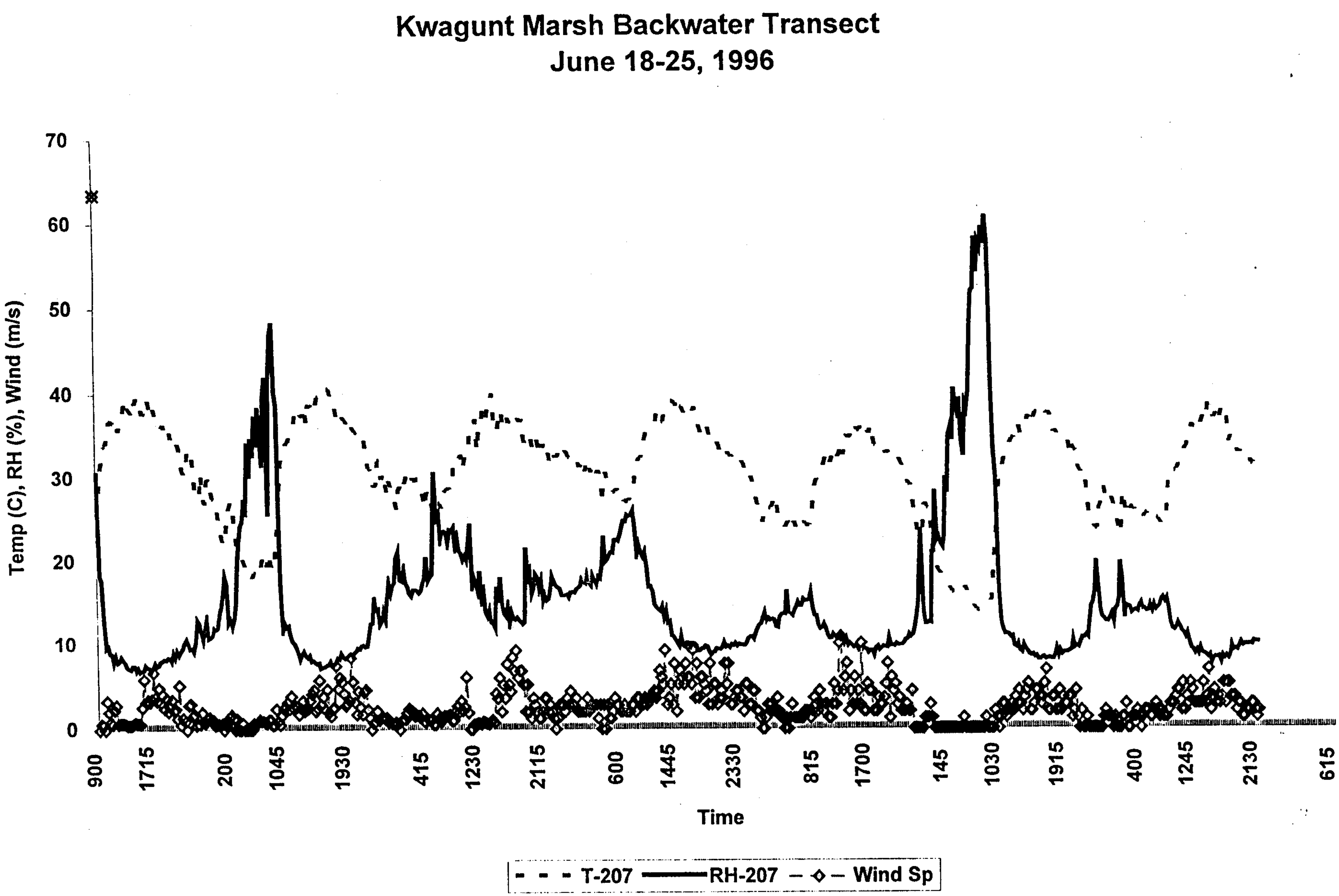


Fig 3.3: An example of diel patterns of temperature ("T-207"), relative humidity ("RH-207") and wind speed ("Wind-Sp") at Mile 55.5R, 189-25 June 1996.

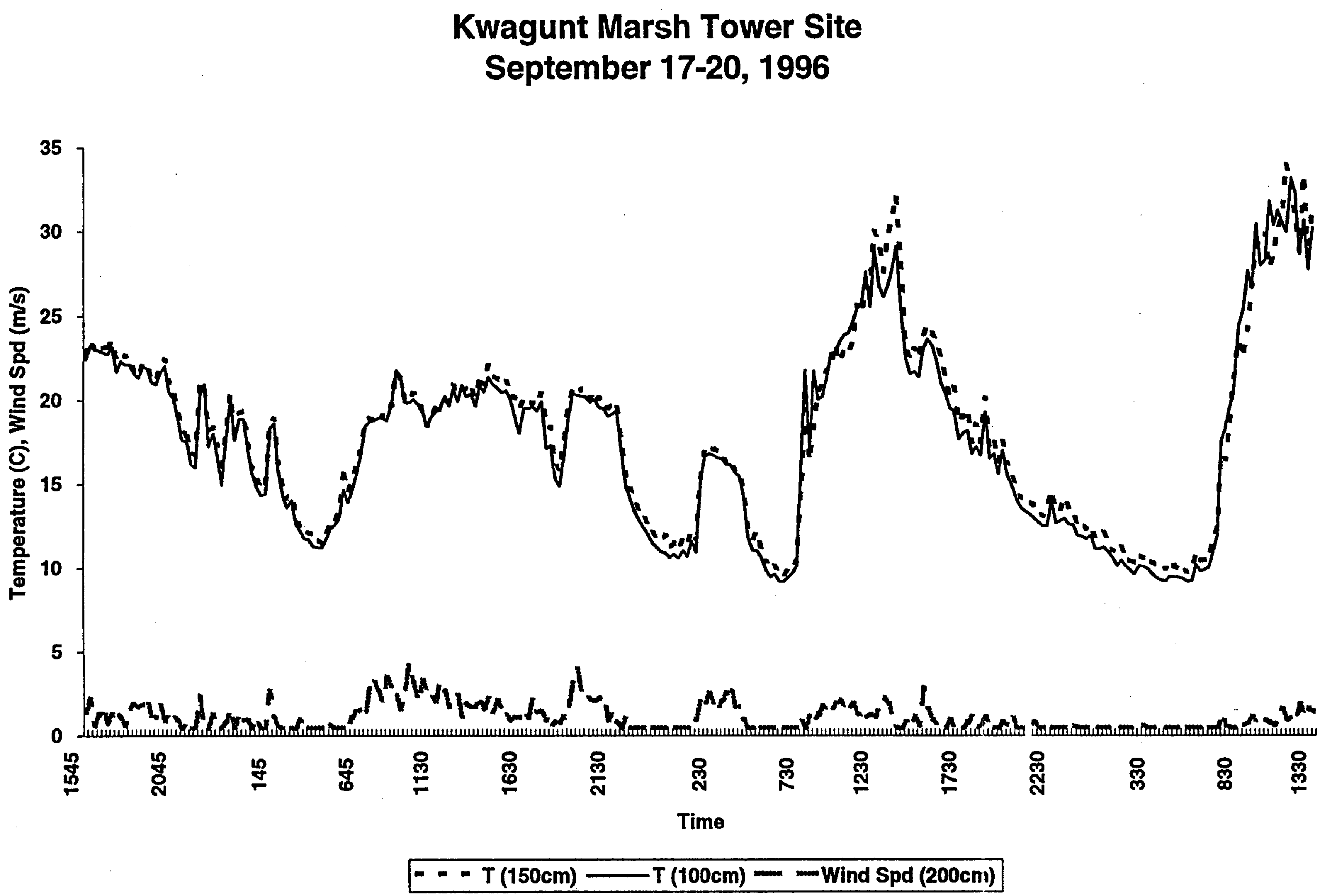


Figure 3.4: Mile 55.5R tower temperature and wind speed data, 17-20 September 1996.

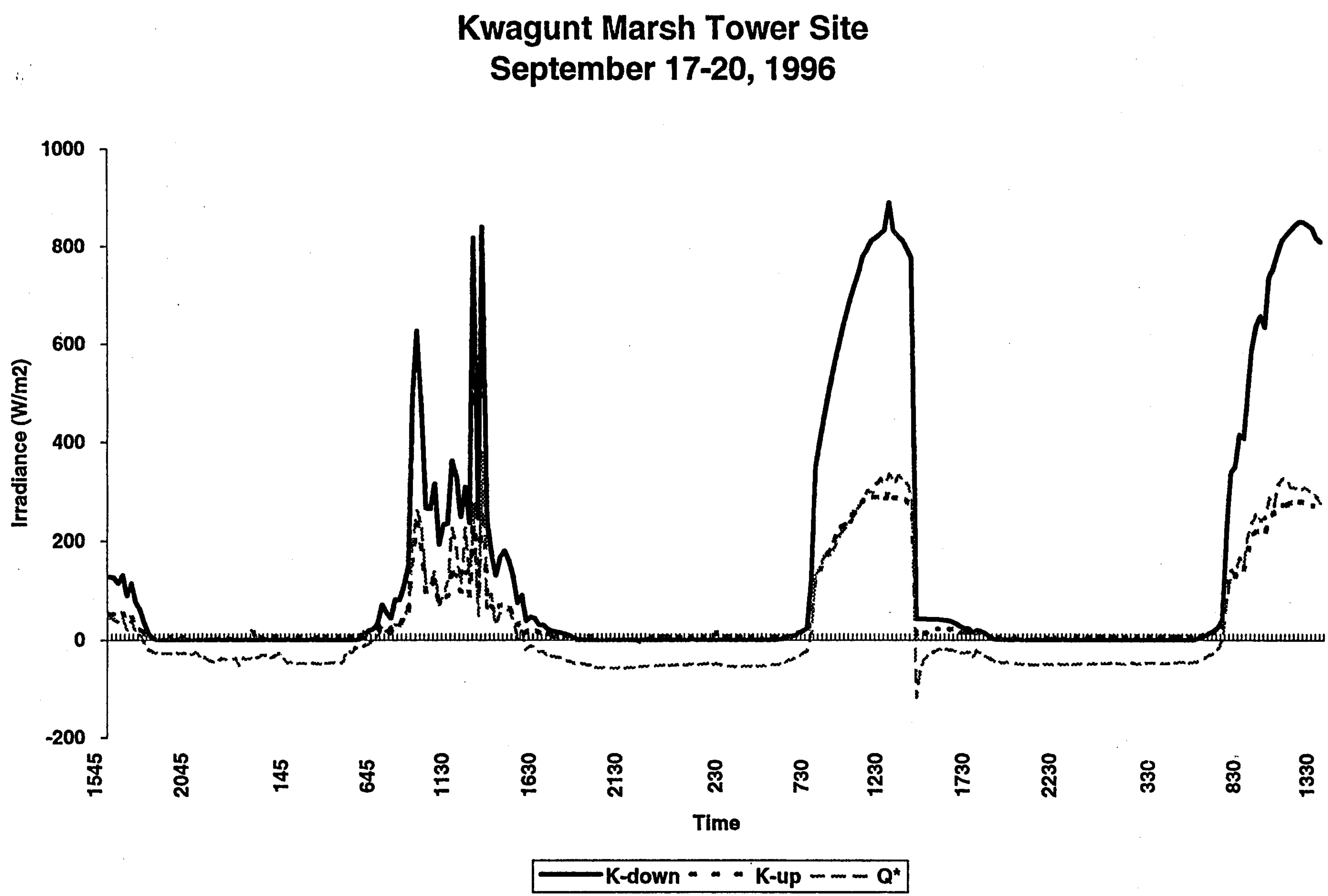


Figure 3.5: Mile 55.5R tower incoming and outgoing radiation and net radiation (W/m²) 17-20 September 1996.

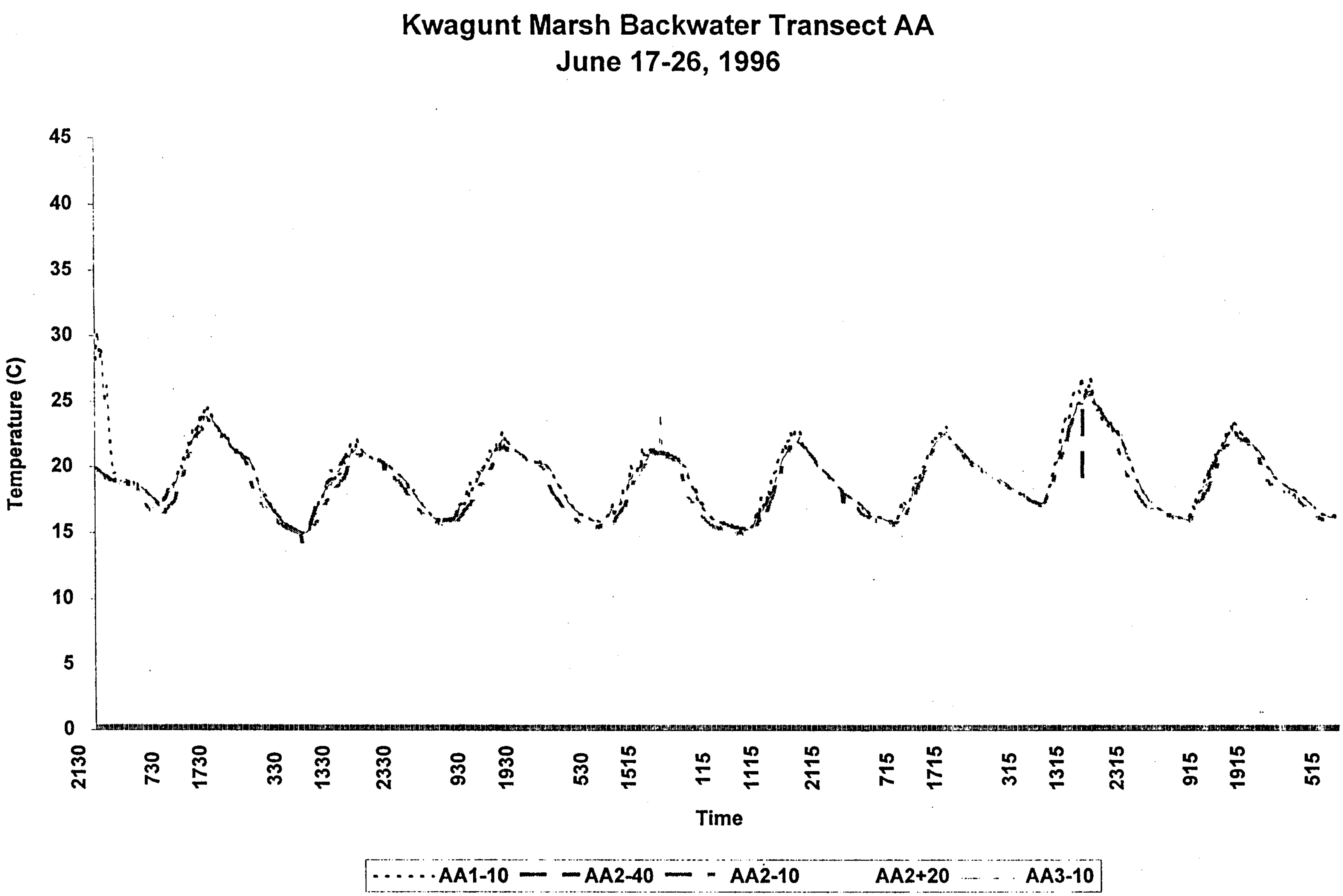


Fig 3.6: Mile 55.5R Transect AA air temperature ("AA2+20") and water temperatures at 10 and 40 cm depth on 17-26 June 1996.

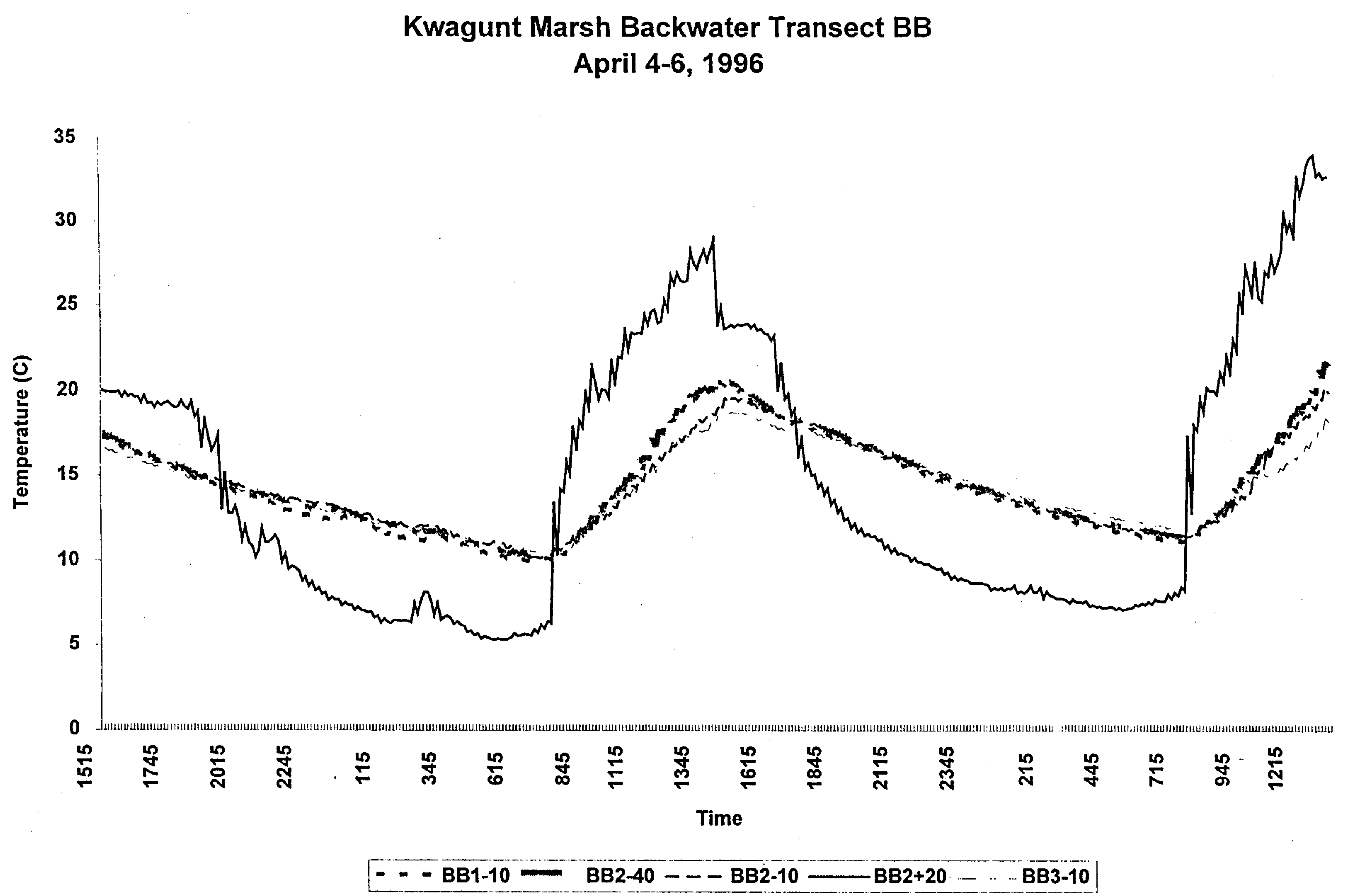


Fig 3.7: Mile 55.5R Transect BB air temperature ("BB2+20") and water temperatures at 10 and 40 cm depth on 4-6 April 1996.

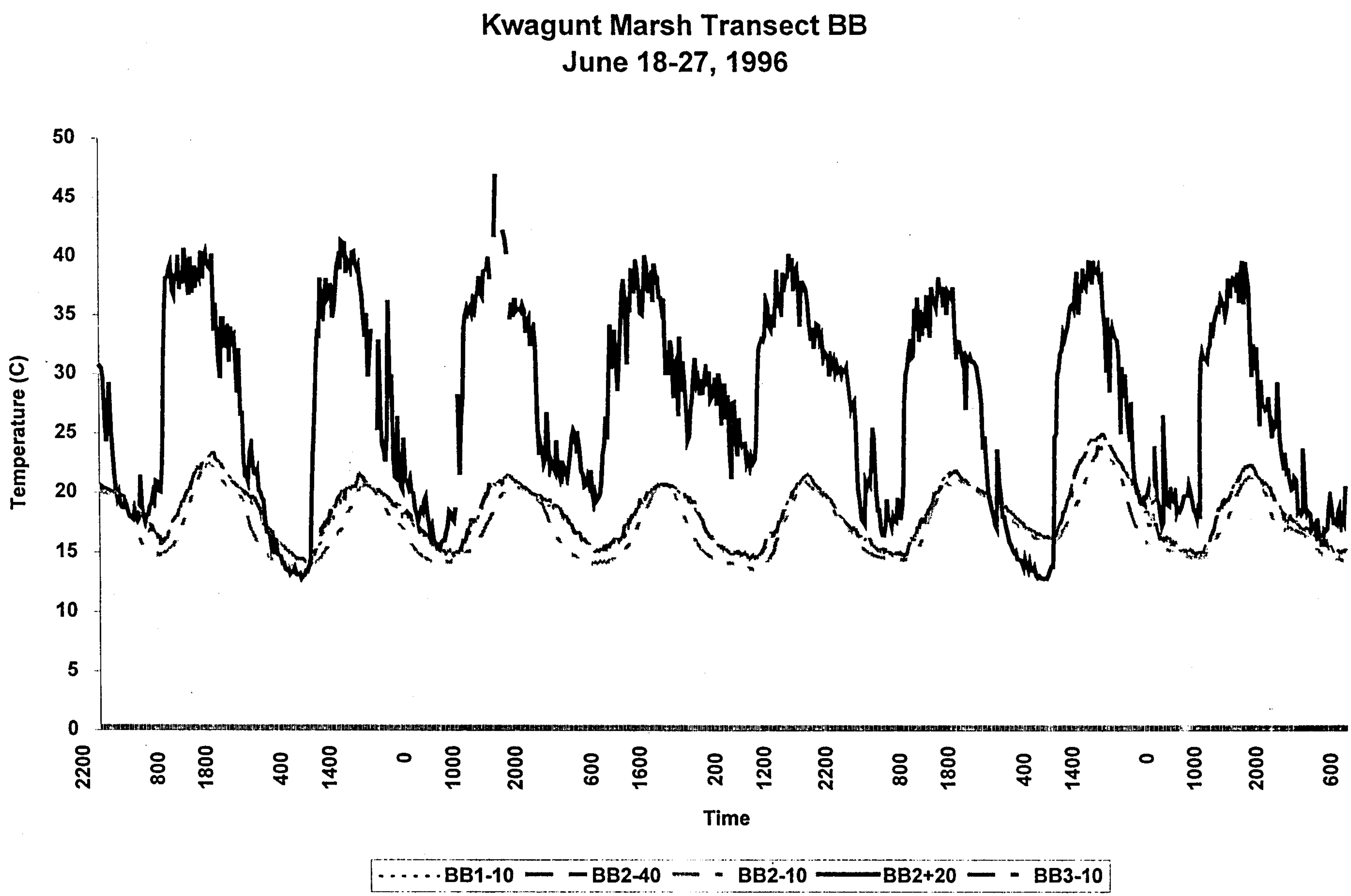


Fig 3.8: Mile 55.5R Transect BB air temperature ("BB2+20") and water temperatures at 10 and 40 cm depth on 18-27 June 1996.

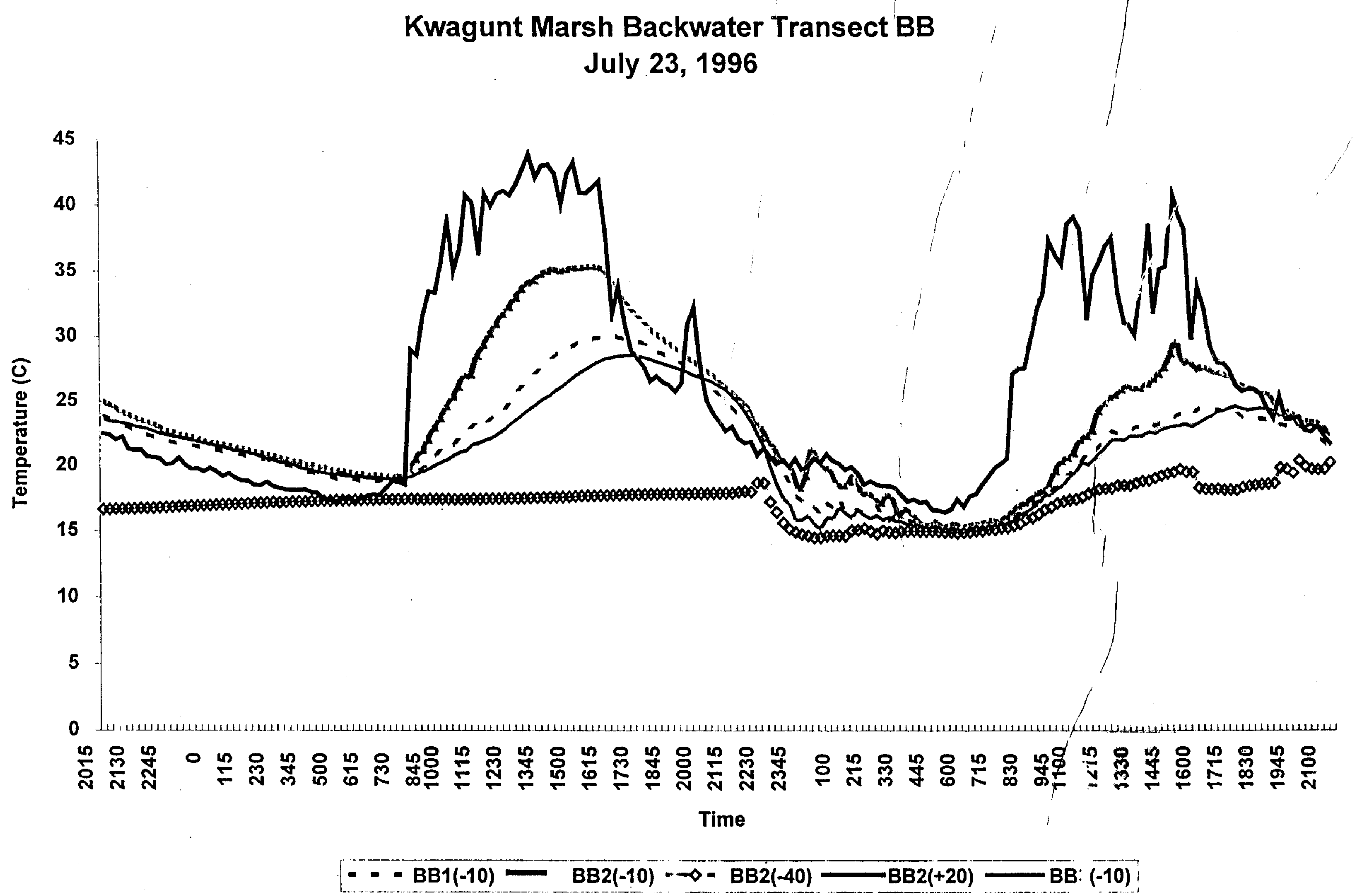


Fig 3.9: Mile 55.5R Transect BB air temperature ("BB2+20") and water temperatures at 10 and 40 cm depth on 23 July 1996.

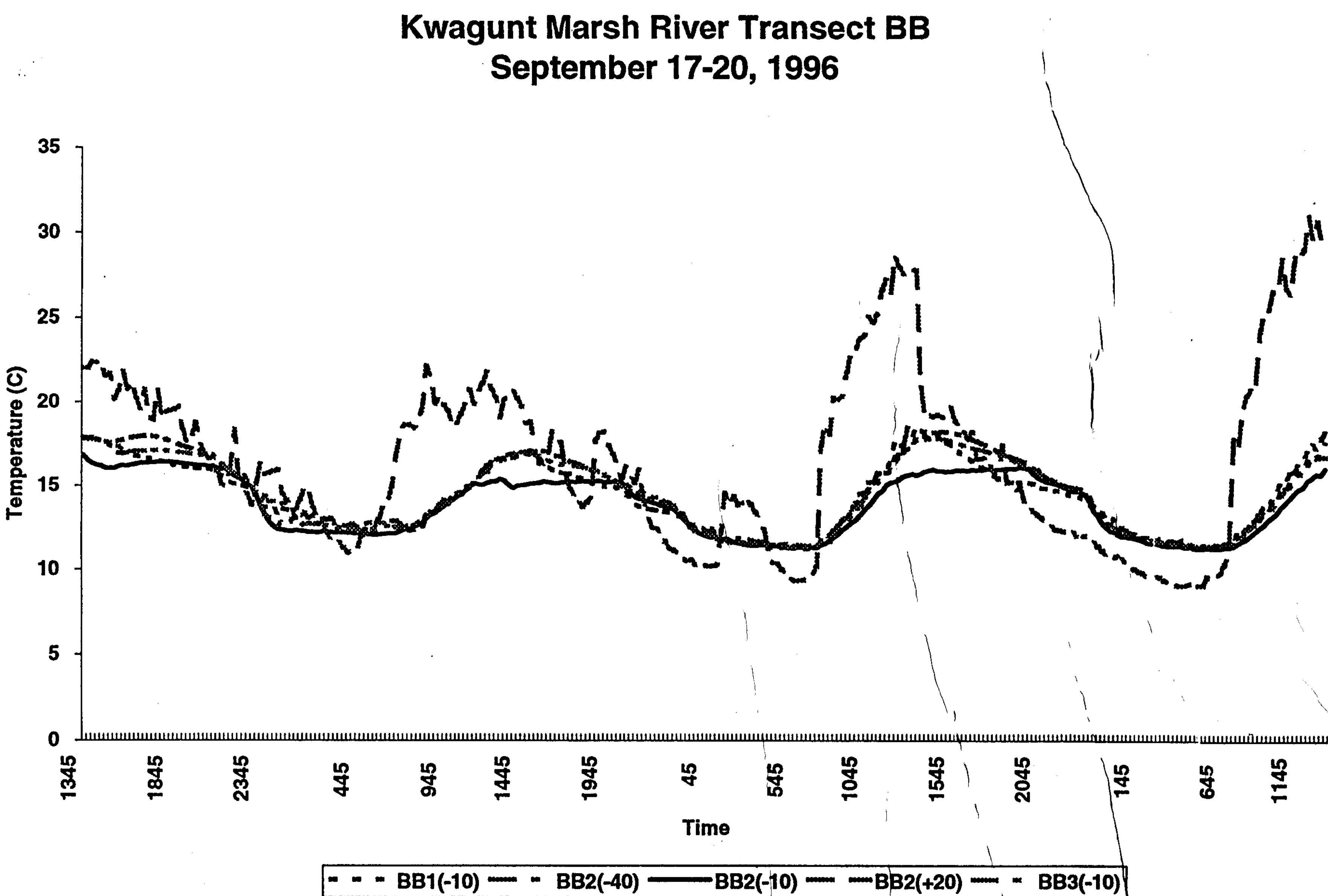


Figure 3.10: Mile 55.5R Transect BB air temperature ("BB2+20") and water temperatures at 10 and 40 cm depth on 17-20 September 1996.

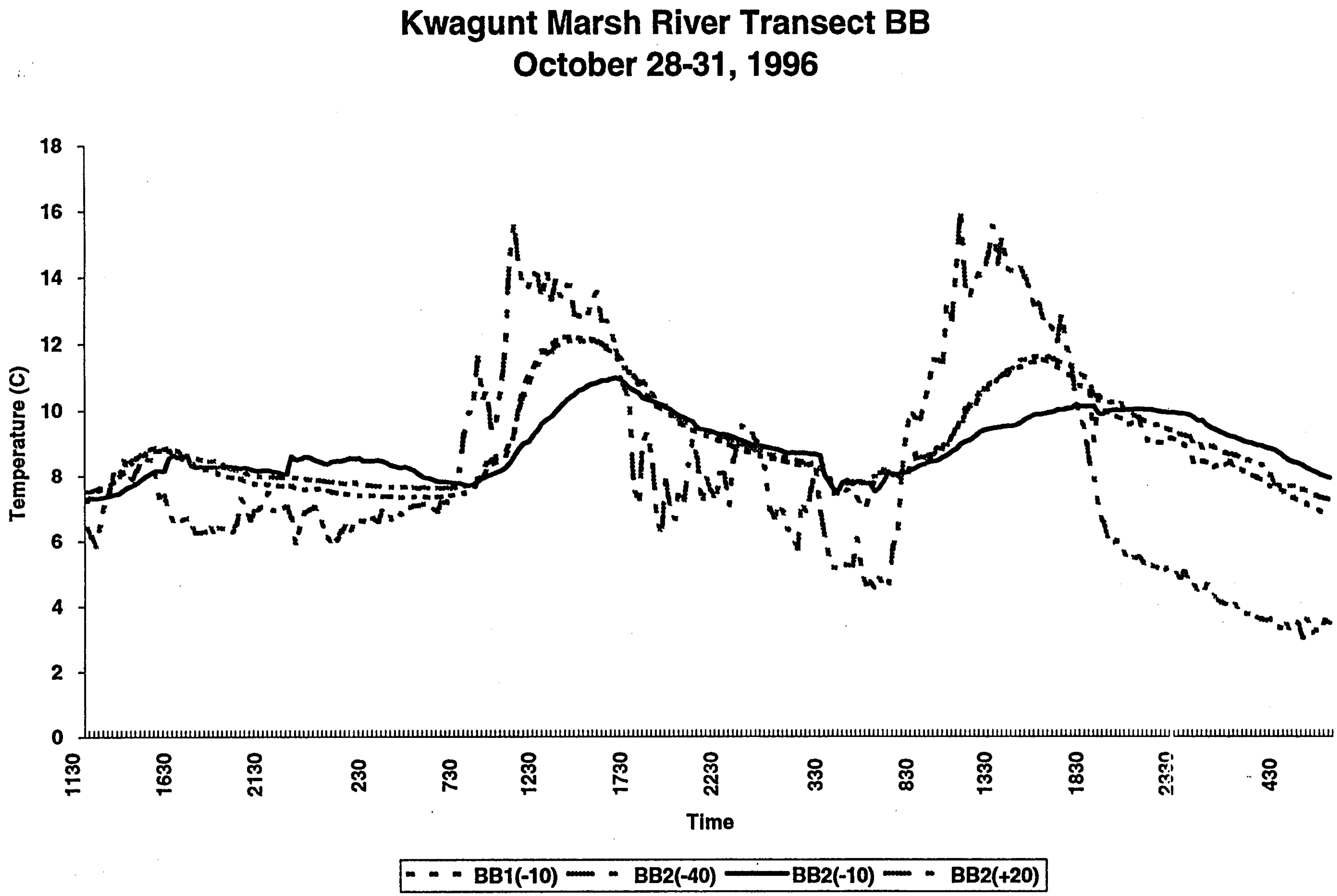


Figure 3.11: Mile 55.5R Transect BB air temperature ("BB2+20") and water temperatures at 10 and 40 cm depth on 28-31 October 1996.

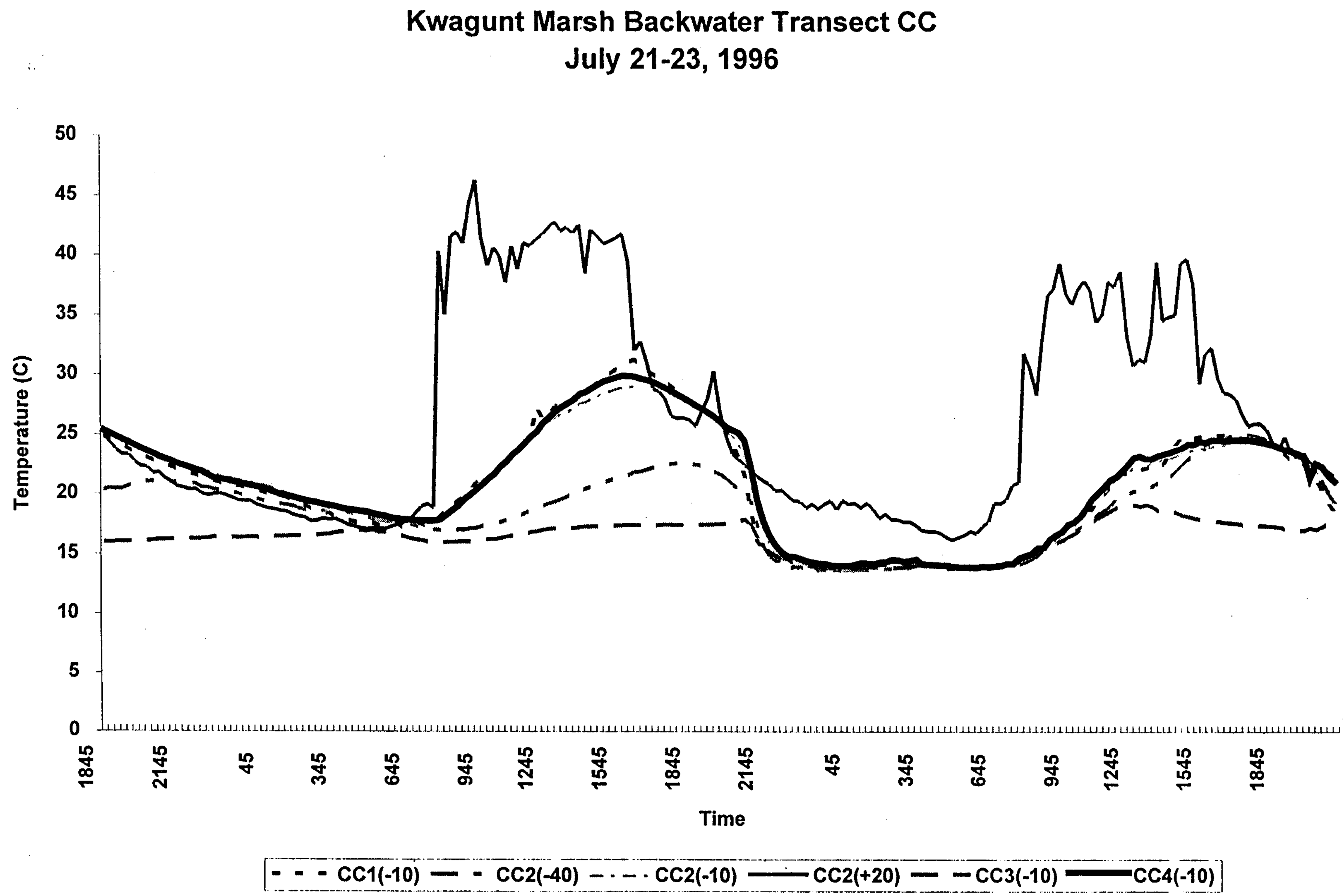


Fig 3.12: Mile 55.5R Transect CC air temperature ("CC2+20") and water temperatures at 10 and 40 cm depth on 21-23 July 1996.

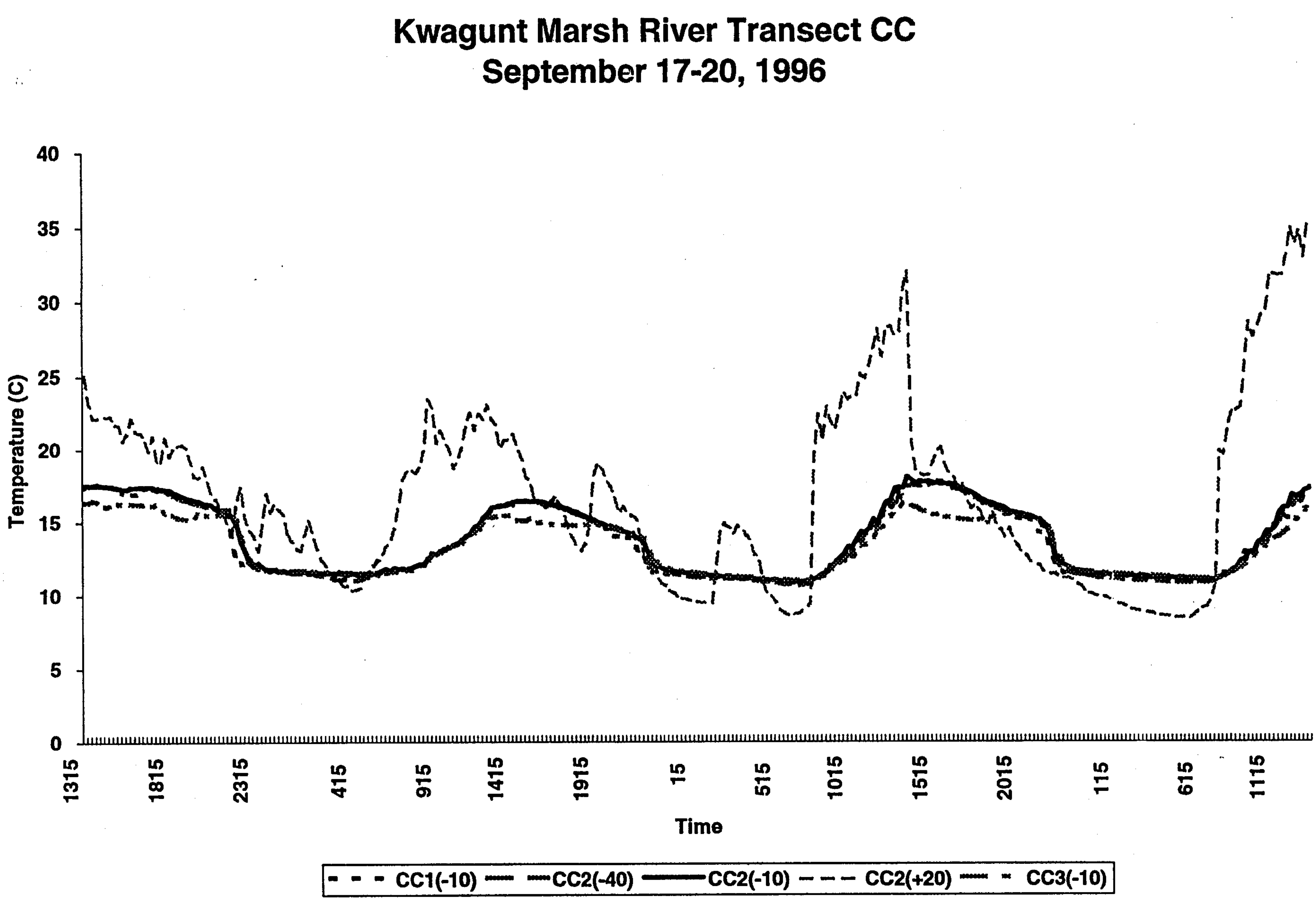


Figure 3.13: Mile 55.5R Transect CC air temperature ("CC2+20") and water temperatures at 10 and 40 cm depth on 17-20 September 1996.

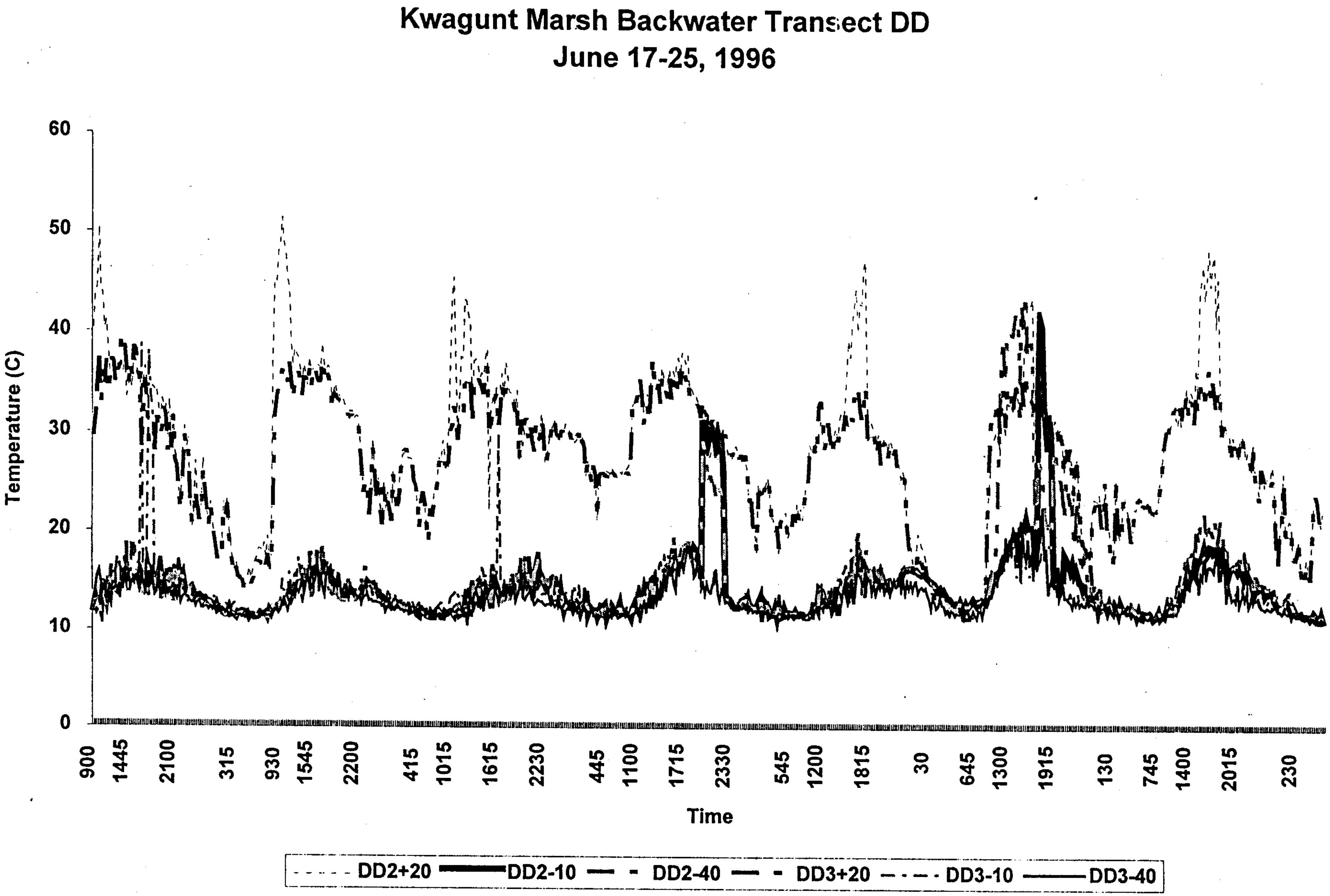


Fig 3.14: Mile 55.5R Transect DD air temperature ("DD3+20") and water temperatures at 10 and 40 cm depth on 17-25 June 1996.

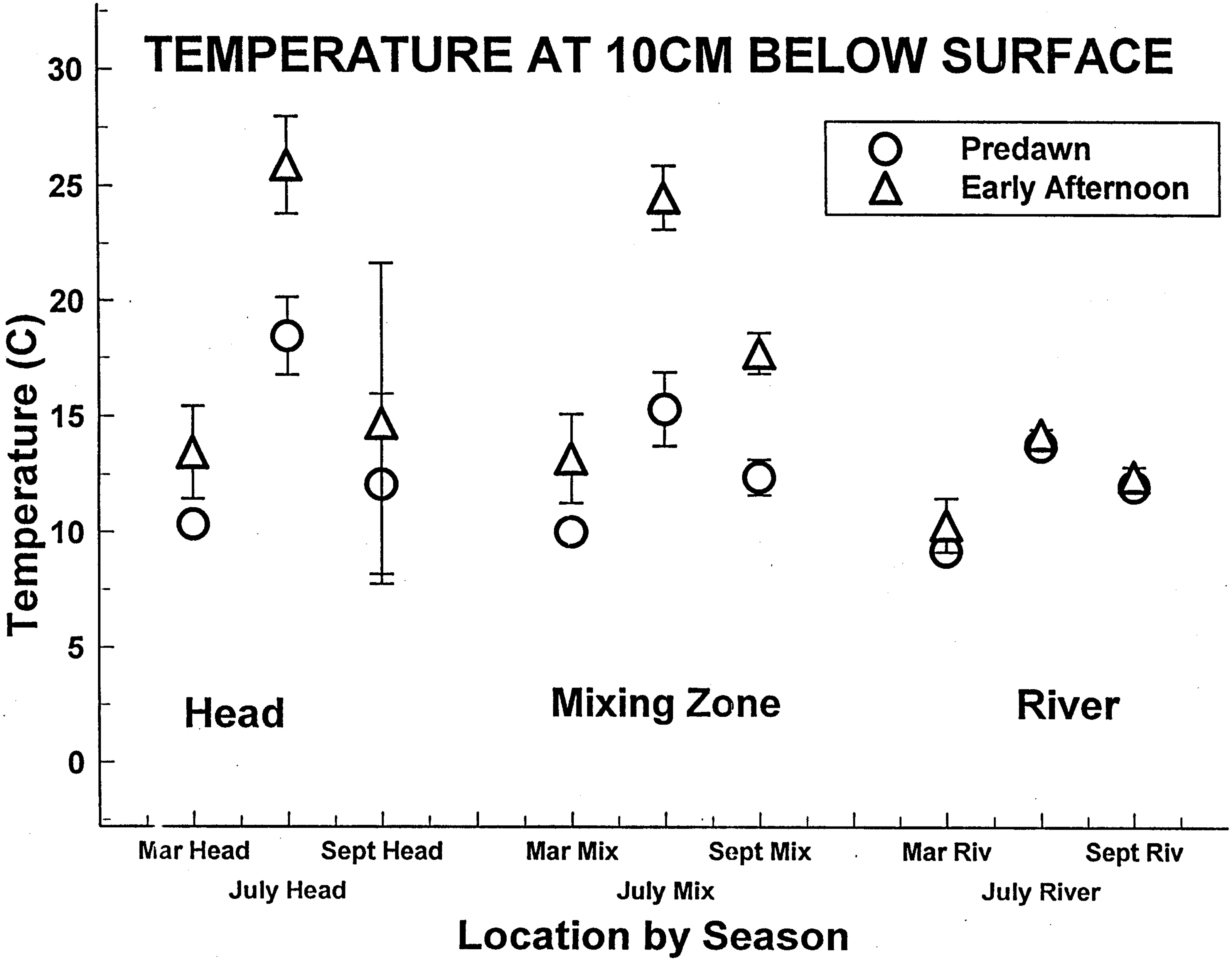


Fig.3.15: Mile 55.5R mean pre-dawn and midday temperatures at 10 cm below the surface in March, July and September in the backwater head, mixing zone and river. Error bars are 1 SE.

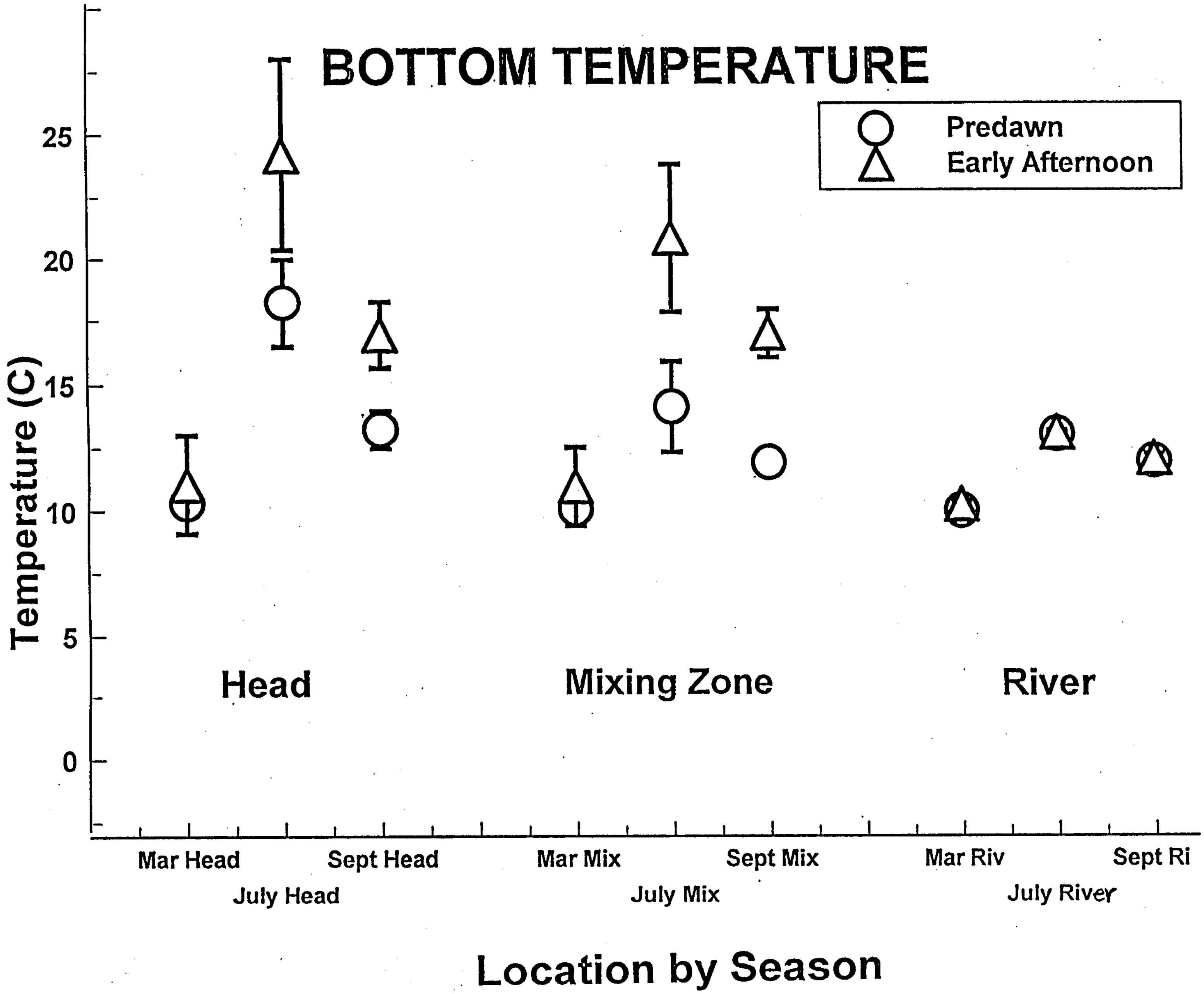


Fig. 3.16: Mile 55.5R mean predawn and midday temperatures at the bottom below the surface in March, July and September in the backwater head, mixing zone and river. Error bars are 1 SE.

4. BIOLOGICAL AND FISHERIES DEVELOPMENT

Background

In addition to estuaries, riverine backwater habitats are widely regarded as being important fish nursery areas; however, rather few integrated biological studies have been conducted. Detailed studies in an upper Mississippi River backwater demonstrated that water clarity plays the single largest role in backwater production, and non-algal suspended sediments reduced water clarity and annual production (Owens and Crumpton 1995). Their study provides a framework for conducting plankton (but not benthos) production studies; however, they did not integrate plankton production and thermal stratification with fish habitat use, nor were they concerned with the rapid changes in velocity and temperature that characterize Grand Canyon backwaters. Analysis of these issues is required to improve understanding of the ecological mechanisms affecting backwater development in Grand Canyon.

Backwater biota in Grand Canyon have been surveyed repeatedly over the past decade (e.g., Maddux et al., 1987; Haury 1988; Hoffnagle 1995). Those data provide some insight into plankton composition and distribution; however, few data exist on spatial or temporal (daily, seasonal, annual and interannual) development of backwater plankton and benthos assemblages, or how such assemblages respond to cold, unsteady mainstream flows.

Backwaters provide important habitat for all young native fish species in the Colorado River (Holden 1978; Valdez and Clemmer 1982; Carter et al. 1985, Valdez and Ryel 1995), and also support all life stages of non-native fathead minnow (*Pimephales promelas*) and plains killifish (*Fundulus zebrinus*). Distribution of these species, and the importance of fish use of backwaters in Grand Canyon, has been documented by Hoffnagle (1995) and were monitored through the Test Flow by the Arizona Game and Fish Department (AGFD).

The extent of post-flood habitat use by fish depends on habitat availability, water quality parameters (especially temperature and dissolved oxygen concentration, DO) and on biological production (food resources). We monitored the Mile 55.5R RCC backwater in 1996, and we plan to use 1997 data to relate physical and lower trophic level development of backwaters to fish distribution and habitat use patterns. Such a study will complement on-going AGFD monitoring and other planned fisheries and Bureau of Reclamation thermal modification research in this system.

Objective 4: Describe backwater biological development in relation to fish habitat use.

Sub-Objective 4a. Determine plankton distribution, standing mass and production.

Methods

We established georeferenced microhabitat sampling sites throughout the Mile 55.5R bar. Temperature, DO, pH, and specific conductance were measured with a Hydrolab™ and those data refine description of microhabitat development during the 1996 growing season. Replicated within-day measurements of dissolved oxygen (DO) were made using a Hydrolab on each transect and in the mainstream (Appendix 4a.1). The difference methods of Owens and Culper (1995) may help explain integrated gross community production from net community production.

This method assumes that daily respiration rates are proportionally equivalent to measured nighttime respiration rates. Sensor calibration was performed in accordance with standard protocols.

Two L water samples were collected from discrete, georeferenced transects in the backwater using a hose and pump system, and we filtered 1 L of each 2L sample through pre-weighed Whatman No. 42 filters for plankton standing mass analyses. The remaining 1 L of sample were filtered through Whatman No. 42 filters, and preserved for plankton composition analyses. Comparable samples were collected in the mainstream.

Results and Discussion

DO varied on a diel basis and in relation to temperature and mainstream flow (Appendix 4a.1). Substantial variation in DO concentration was observed in the RCC backwater from pre-dawn ("a.m.") to mid-day ("p.m.") in the mid-summer months, with values dropping substantially below that in the mainstream (ca. 10 mg/L) at night and rising to supersaturation (>13 mg/L) during the day (Fig. 4a.1). This reflects nocturnal respiration of the benthos and water column organisms, as well as the production of oxygen by benthic macrophytes during the day. Additional analyses of these data are underway.

Plankton sampling revealed little AFDM of plankton in the RCC backwater. June and July plankton AFDM values were <9 mg/L (Appendix 4a.2). Additional data are being compiled for the 1997 report.

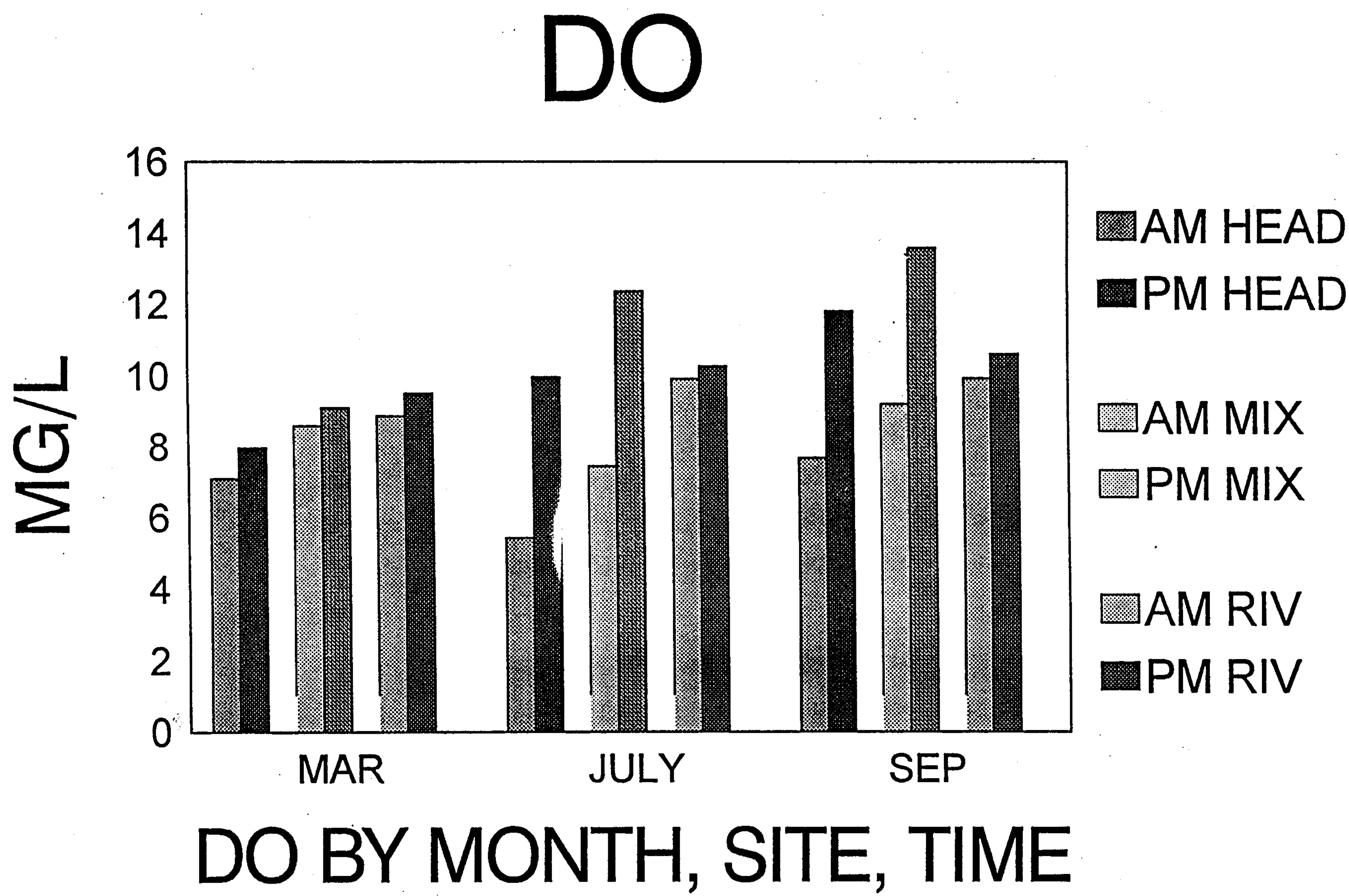


Fig. 4a.1: Mile 55.5R mean predawn and midday dissolved oxygen concentrations (mg/L) at the backwater head, in the backwater mixing zone, and in the mainstream at 15 cm above the floor in March, July and September 1996.

Sub-Objective 4b. Determine benthic distribution, standing mass and production.

Methods

We used a petite Ponar dredge (0.023 m^2) and other area-based benthic ooze sampling methods to monitor benthos on the transects in the Mile 55.5R backwater. We focused our analyses on three primary aquatic zones: the head (or back) of the backwater which was relatively isolated from the river's influence; the mixing zone from the middle of the RCC to the mouth; and the sand-floored river channel adjacent downstream from the reattachment point.

Invertebrates were sorted and preserved in 70% EtOH for taxonomic analyses in the laboratory. Fine sediments were seived through a 1.0 mm mesh filter to collect ooze invertebrates. Volume and area of sediment were measured, and sediment wet mass was measured, with a subsample saved for grain size analyses (Objective 1b-c, above).

Results and Discussion

Macrophyte ash-free dry standing biomass (AFDM) at Mile 55.5R was always considerably higher in the RCC mixing zone than in the adjacent sand-floored mainstream (Fig. 4b.1; Appendix 4b). Macrophyte AFDM in the RCC was lowest immediately following the Test Flow, and increased 5-fold to 34 g/m^2 in September, becoming senescent thereafter. Initially, several species colonized the post-flood RCC, including *Chara* sp., *Potomogeton pectinatus* and *Elodea canadensis*. By the end of the growing season, the floor of the RCC at a flow of 250 m^3/s was almost completely covered with a dense bed of *Elodea canadensis*, and the other macrophyte species had largely disappeared. Macrophyte cover returned to near 0 in February 1997 (Stevens, personal communication).

Benthic invertebrate composition and AFDM was strongly altered and reduced by the Test Flow (Fig. 4b.2; Appendix 4b). Benthic composition was strongly dominated by oligochaetes and *Chironomus* sp. midges prior to the Test Flow, with densities in excess of 30,000 organisms/m^2. Also, AFDM was substantially higher in the RCC backwater than in the adjacent sand-floored mainstream. Immediately following the Test Flow, benthic invertebrate AFDM in the head and mixing zones of the RCC had decreased by an order of magnitude and almost no invertebrates were collected in the mainstream (Fig. 4b.2). Benthic AFDM increased progressively over the 1996 growing season, with September AFDM approximately 20% of the pre-flood levels. The summer composition included: ostracods > oligochaetes > *Chironomus* sp. midges > *Physella* sp. snails > *Fossaria obrusa* snails > *Pisidium* sp. clams > nematodes.

Predatory aquatic invertebrate species increased in abundance in the water column through the 1996 growing season in the RCC backwater. October 1996 seine hauls of the RCC revealed hundreds of Corixidae, and numerous Notonectidae and Odonata (mostly Libellulidae). Thus, the potential for predation on small fish increased considerably through the growing season.

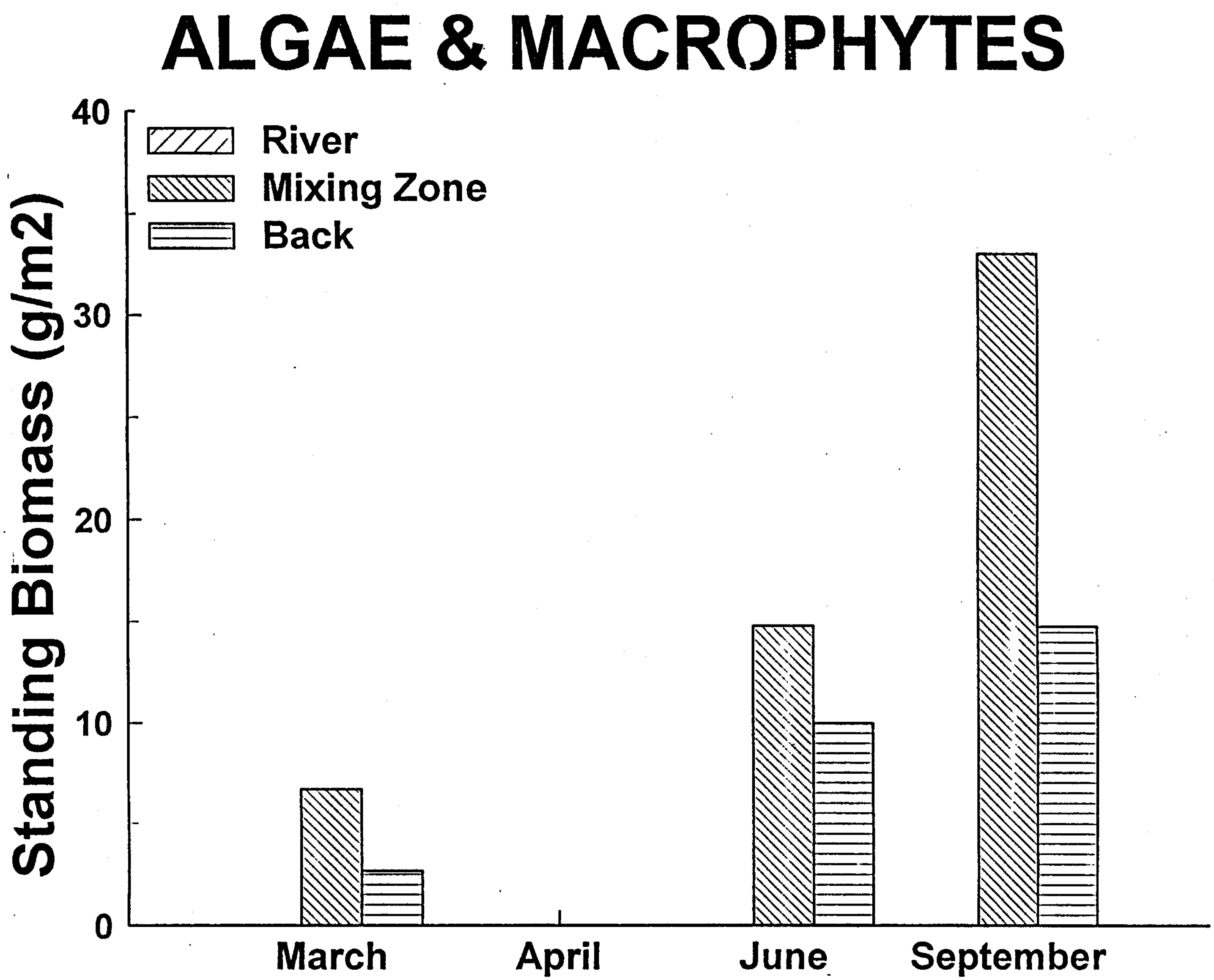


Fig. 4b.1: Mile 55.5R mean macrophyte ash-free dry standing biomass (g C/m^2) at the backwater head, in the backwater mixing zone, and in the mainstream during the 1996 growing season.

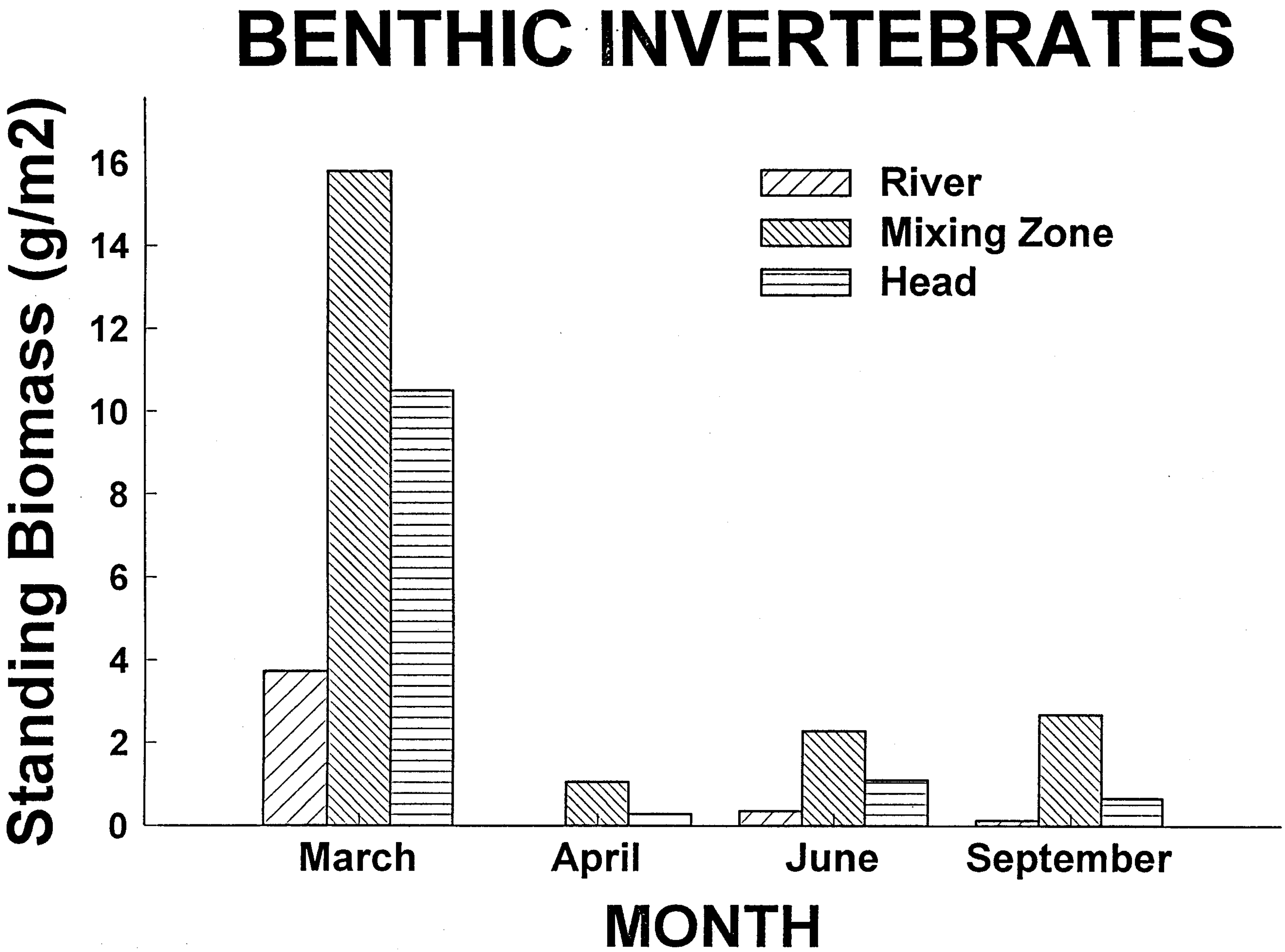


Fig. 4b.2: Mile 55.5R mean benthic ash-free dry standing biomass (g C/m^2) at the backwater head, in the backwater mixing zone, and in the mainstream during the 1996 growing season.

Sub-Objective 4c. Determine fish distribution.

Methods

Fish distribution was monitored using an index of catch-per-unit-effort (CPUE), seasonal seining hauls by AGFD, and by direct observations. Minnow traps were used as a non-sacrificial, non-disruptive means of capturing small fish. Six minnow traps were set in each of three microhabitats: shallow backwater, interaction zone backwater, and mainstream channel margin. Traps were checked at least every 12 hr during each 48 hr sampling period. All fish captured were identified to species, and lengths were measured. We examined each individual for external parasites and injuries, but found none. CPUE was calculated as the number of fish captured/trap/hr set. CPUE provides a relative index of the number of fish in each microhabitat of the backwater between samples and will document fish distribution.

Results and Discussion

CPUE of young fish was higher in the RCC backwater than in the mainstream throughout the growing season, except in April (Fig. 4c.1; Appendix 4c). After July, small fish were rare in the river, but remained abundant in the RCC.

The Mile 55.5R RCC backwater was extensively used as a rearing environment by native flannel-mouth sucker and speckled dace, and non-native carp (*Cyprinus carpio*) (Fig. 4c.2). Young flannelmouth suckers were abundant in June, and decreased in abundance through September. Interestingly, flannelmouth suckers >120 mm in total length were captured in minnow traps in July and September. Those fish were probably 1995 cohort, indicating that the prior year's age class re-occupy backwaters during the mid-summer months. Schools of >100 young dace and suckers concentrated in the shallow, clear head of the backwater in June and July. Our data demonstrated that adult dace and all young native fish densities were higher in the backwater than in the adjacent river. The backwater was also used in late summer by adult carp, and nocturnally during the spring by adult rainbow trout.

Mature carp were observed moving into the macrophyte beds in the backwater during the nighttime hours in middle and late summer. Although we did not observe actual spawning behavior, carp spawning behavior is often associated with warm water and macrophyte beds (Lechleitner 1992), and the numerous small carp observed in September and October indicated that carp spawned in the RCC.

High densities of extremely small (<22 mm) flannelmouth suckers were observed in the head of the backwater in June, nearly 100 m from the river. These observations suggest that flannelmouth suckers may have also spawned in the backwater. If they did not spawn in the backwater, they either spawned in the mainstream, in the warm springs at Mile 30, or in the Paria River (Mile 1).

Rainbow trout (*Oncorhynchus mykiss*) were observed moving into the RCC at night from March through June. The trout moved into the backwater at night and out as flows decreased during the day. During the 226 m^3/s post-flood constant flow, the RCC backwater was perched and disconnected from the mainstream. Backwater dissolved oxygen levels decreased to <4 mg/L and maximum mid-day temperature exceeded 20°C. On the third day of these conditions, we observed mortality of rainbow trout. Therefore, perched RCC water quality can result in fish mortality even during the relatively cool spring months.

Fish > 40 mm caught during each sampling period were marked with a small, distinctive fin clip (Stevens et al. 1996). The Jolly-Serber mark-recapture procedure was proposed for analysis of population size in the backwater (Krebs 1989); however, better population estimates were derived using AGFD netting data.

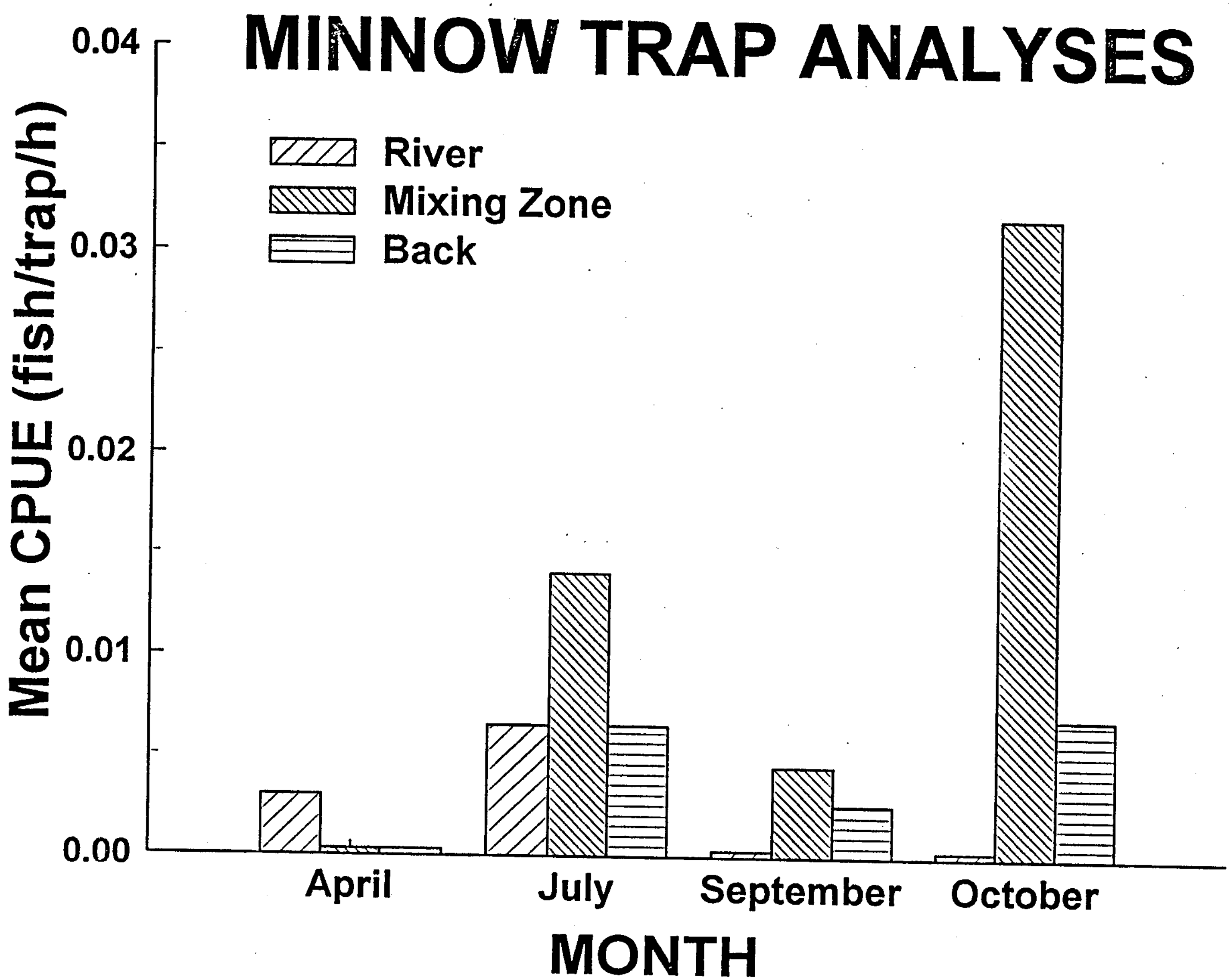


Fig. 4c.1: Mile 55.5R mean minnow catch per unit effort (fish $trap^{-1}hr^{-1}$) at the backwater head, in the backwater mixing zone, and in the mainstream during the 1996 growing season.

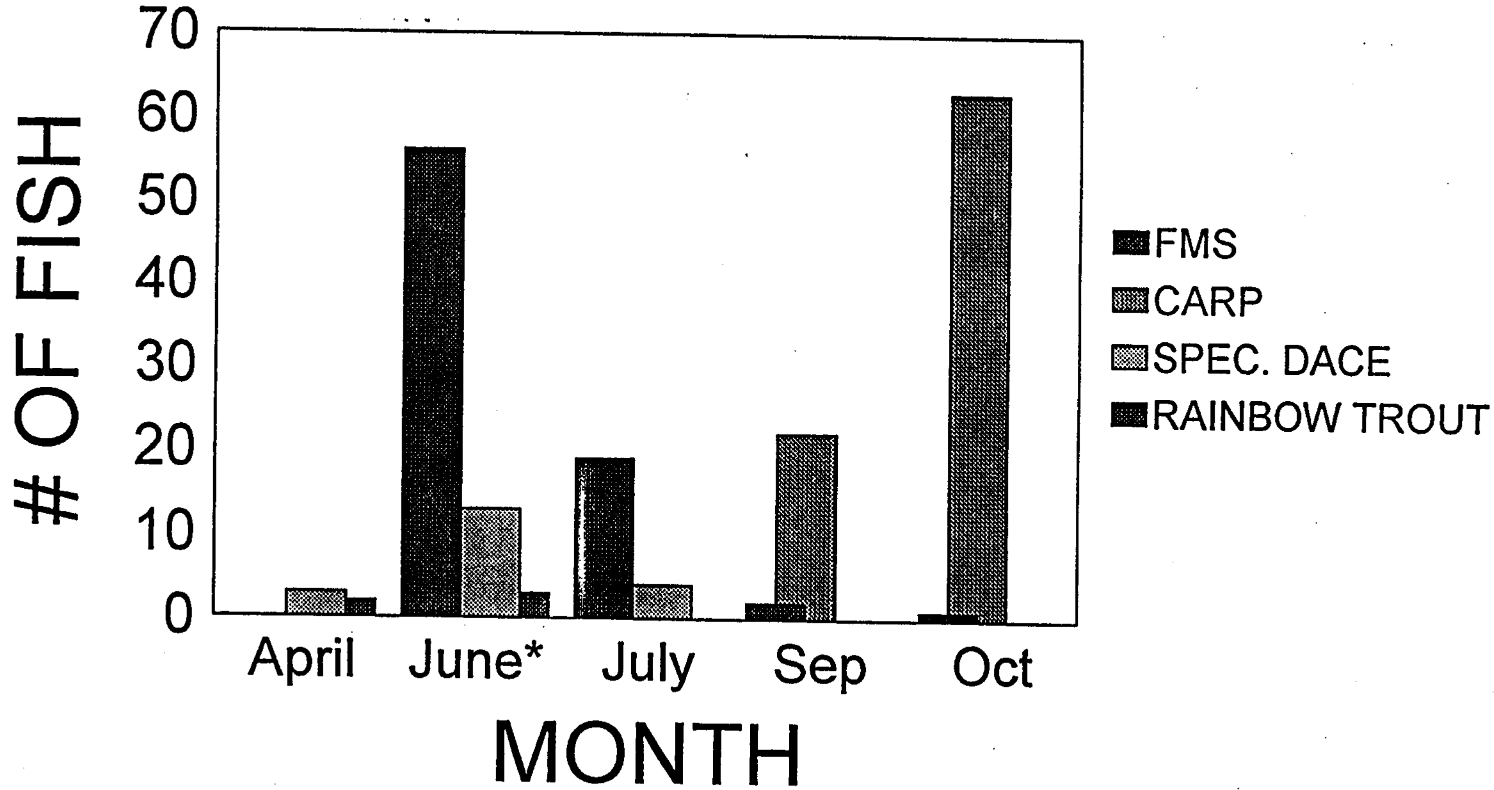


Fig. 4c.2: Mile 55.5R fish composition by species during the 1996 growing season.

Sub-Objective 4d. Determine fish diet.

Methods

We collected up to 10 fish of each species (no endangered species were encountered) from the Mile 55.5R RCC backwater to determine fish diet. Specimens were preserved in 70% EtOH, and relevant location data were recorded. In the laboratory, diet items were identified to the lowest taxonomic level possible without additional expenditure of funds, and the percent composition, by number and dry weight, and frequency of occurrence of food items in the diet are being determined (Bowen 1983). Food electivity is being evaluated using the methods of Strauss (1979), and departure from Strauss's Index are being determined by t-tests (Mallin et al., 1985) and serial Bonferonni tests (Rice 1989). Changes in stomach contents and electivity indices are being tested by analysis of variance and planned comparisons (Sokal and Rohlf 1981). Analyses of fish diet data (Appendix 4d.1) are being compiled and will be presented in the 1997 report.

A pilot growth experiment was conducted on young-of-year flannelmouth sucker, following discussions with AGFD and NPS staff. The experiment was conducted to test y-o-y flannelmouth sucker responses to different water quality conditions. The experiment was conducted for 6 d at Mile 55.5R, and consisted of 6 minnow traps, each containing 3 y-o-y flannelmouth suckers, in three locations (backwater head, backwater head = mixing zone, and the mainstream). Length and mass of fish were measured daily.

Results and Discussion

The pilot growth experiment demonstrated that fish lost mass in all settings, because the fish were handled daily, rather than just at the beginning and end of the experiment (Appendix 4d.2). However, the experiment did demonstrate measurable change in condition over a week-long period and is worth repeating. This form of bioassay can be used to determine fish responses to various water quality conditions.

5. INTEGRATED DATABASE DEVELOPMENT

Objective 5: Develop a database that will allow interrelationship of physical backwater development (geomorphic, nutrient flux, climate/river/thermal stability) and biological development (benthos, plankton and fish habitat use).

Synthesis of these multidisciplinary data initially involves database development for several purposes. 1) We are compiling individual study components data (e.g., geomorphology or fish habitat use). We plan to relate those data to system-wide patterns within the individual disciplines through the reporting and planned Test Flow Symposium in April 1997. 2) We are developing an integrated conceptual backwater model which focuses on interactions between geomorphic development (e.g., spatially explicit habitat availability), nutrient dynamics and thermal stratification, with plankton/benthic production, and fish habitat use over diel and seasonal time scales. 3) Our data will allow future quantification of this conceptual model using empirical and modeled output, descriptive statistics, analyses of variance, and multivariate analyses. 4) Lastly, following data collection and management (which is occurring through this first year's report, we plan to develop a site-specific quantitative model to relate physical and biological parameters with mainstream flows.

6. GIS INTEGRATION

Objective 6: Compile data so that it can be linked to the GCES GIS for predictive purposes in future monitoring and research.

All 55.5R data have been surveyed in relation to existing local georeferencing controls and these survey data conform to the georeferenced, electronic format of the existing Department of Interior GIS for use in future backwater monitoring and continued research, as well as investigation of sediment dynamics, erosion monitoring, and thermal modification research.

CONCLUSIONS AND MANAGEMENT CONSIDERATIONS

In summary, our 1996 data demonstrate that although substantial geomorphic rejuvenation of the Mile 55.5R backwater did not occur, the Test Flow strongly affected backwater morphology and hydrogeochemistry, which in turn influenced subsequent biotic development. Although surface flow velocities reached ca. 0.9 m/s and were sufficient to deposit up to 1.8 m of new sand, these velocities were insufficient to scour the compacted silt floor of the RCC, preventing major restructuring of the RCC bed. Deposition of new sand reduced maximum RCC volume by at least 20%, and produced a narrower but not deeper backwater. Low tributary inflows during 1996 limited aggradation of the RCC, therefore hyposmetric relationshiops established during the Test Flow have remained essentially unchanged.

Hydrogeochemical alteration of sandbars during flooding influences subsequent nutrient availability and spiraling. Hydraulic conductivity decreased by 20 to 40% under as much as 1.8 m of newly deposited sediment, affecting groundwater flow rates. Non-purgeable organic carbon (NPOC) in sandbar groundwater decreased in concentration after the Test Flow from 85% to 278%. NPOC concentrations at Mile -6.5R increased from 3.95 (+/- 1.7) to 7.32 (+/-10.5) mg/L, and had not recovered by 228 days after recession. NPOC concentrations at Mile 55.5R increased gradually during recession and had doubled by June of 1996. Ammonium concentration greatly increased in bar groundwater immediately after the Test Flow as buried vegetation began to decompose, and ammonium concentrations remained elevated during the 1996 growing season.

The altered geomorphic condition of the bar, coupled with climate and mainstream flow patterns and temperature, produced thermal warming and stratification in the backwater. Thermally advantageous conditions existed for fish at least from June through September, as compared to the mainstream. Little plankton existed or developed in the backwater throughout the growing season. Benthic macrophytes were scoured from the RCC backwater by the Test Flow, but increased to levels approximately 5-fold greater than pre-Test Flow levels by September. Benthic invertebrate standing mass was reduced by approximately an order of magnitude by the Test Flow, and approximately doubled over the 1996 growing season, reaching 20% of the pre-Test Flow standing mass levels by September. By the end of the growing season large populations of invertebrate predators (aquaic Heteroptera and Odonata nymphs) developed in the backwater.

Native and non-native fish occupation of the backwater varied on a daily and seasonal basis. Although native fish were numerically dominant in the backwater in the spring and summer, we observed trout moving into the backwater at night (during high flows) and out of the backwater during the morning as mainstream flows decreased. Speckled dace and flannelmouth sucker young-of-year (and previous year's cohort of flannelmouth sucker) were more numerous in the backwater than in the river during all

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