Effects of sediment releases from a reservoir on stream macroinvertebrates

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Abstract

Effects of sediment release from Guernsey Reservoir on macroinvertebrates of the North Platte River, Wyoming, were investigated during summer 1981. Suspended solids concentrations during sediment release increased from <20 mg l^{-1} to >300 mg l^{-1}. Because fine particulates remained in suspension, mean particle size of substrates was unaltered. Densities of chironomids decreased 90% + during sediment release but recovered to initial levels in 3 weeks after the release ended. Densities of mayflies and oligochaetes increased. Changes in benthic populations were highly correlated with increases in suspended solids.

Introduction

Accumulation of sediment in reservoirs and subsequent reductions in storage capacity have become an increasingly serious problem (Brown 1975). One method of extending the useful life of reservoirs is flushing of profundal sediments (Simons 1979). Although the effects of reservoirs on many aspects of lotic ecosystem processes have been documented (Ward & Stanford 1979), effects of sediment release have received little attention despite potentially extreme consequences (Nisbet 1961).

Substrate type is a major determinant of macroinvertebrate distribution and abundance (Cummins & Lauff 1969; Cummins *et al.* 1966; Hynes 1970). Each species shows distinct preferences for particular substrates as a consequence of respiration requirements, food-gathering mechanisms, case-building behavior, and other life history characteristics (Cummins 1973; Cummins *et al.* 1966; Mackay 1977; Rabeni & Minshall 1977). Releases of reservoir sediments are expected to adversely affect macroinvertebrate communities by altering substrates, increasing suspended solids, and introducing potential toxins (e.g., dissolved sulfide).

Effects of settled sediment vary with amounts deposited. Slight deposition has little effect (Bjornn *et al.* 1977; Rabeni & Minshall 1977), whereas heavy amounts greatly decrease populations (Chutter 1968; Cordone & Kelly 1961; Gammon 1970; Nuttall & Bielby 1973).

Increases in suspended solids without deposition can affect benthic populations. Gammon (1970) found that increases of 20–80 mg l^{-1} above normal levels caused a 45–70% reduction in total numbers. Reductions occurred as organisms drifted downstream, and drift rates were linearly related to suspended solids concentrations. Rosenberg & Wiens (1975) also found increased rates of drift when bank sediments were experimentally introduced into a stream channel. However, the number of organisms drifting was independent of suspended solids concentrations. Hamilton (1961) found no change in numbers of organisms exposed to high concentrations of sand and silt in suspension.

Our study describes the effects of sediment release from Guernsey Reservoir, located on the North Platte River in southeastern Wyoming, on downstream populations of macroinvertebrates. Because downstream flows depend on irrigation

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demand, the river bed is dry from October to April. Thus diversity and density of macroinvertebrates are very low after flows resume in spring.

Since 1936, an annual flushing of reservoir sediments, known locally as the 'silt run,' has been conducted during July and August to reduce bank erosion and seepage losses in downstream irrigation canals. Because flows from an upstream reservoir are used to flush sediments from Guernsey Reservoir, discharge and most water quality parameters vary little from pre-silt run levels. The principal environmental effects of the silt run are an increase in suspended solids and potential deposition of fine particulates in stream channels. Objectives of the silt run study were to compare changes in densities of macroinvertebrates with *a priori* predictions, to quantify the relationship between biotic and environmental change, and to assess the relative contribution of suspended solids and settled solids to changes in abundance of macroinvertebrates.

Experimental design

Two study sites were selected after preliminary sampling in June (Fig. 1). Site 1 was located 4 km downstream from Guernsey Dam. Substrates consisted of cobbles one-half buried in a clay 'armor'. Site 2 was 3 km downstream from Whalen Dam, a low-head structure that diverts river flows into large irrigation canals. Substrates were cobble and gravel with little armor. Suspended solids concentrations were expected to decrease at Site 2 during the silt run as materials settled out behind Whalen Dam. A spatial control site was not present because of extreme flow fluctuations that occurred upstream from Guernsey Reservoir just before the silt run.

Five taxa of macroinvertebrates were chosen for intensive study: *Baetis insignificans* McDunnough (Ephemeroptera), *Tricorythodes minutus* Traver (Ephemeroptera), Orthocladiinae spp. (Diptera, primarily *Orthocladius* sp.), Chironomini spp. (Diptera, mostly *Limnochironomus* sp.), and Oligochaeta spp. These taxa comprised 95% of total numbers before the silt run.

B. insignificans is a small, streamlined mayfly that prefers upper surfaces of coarse substrates in moderate currents. Baetid mayflies in general are tolerant of high concentrations of suspended solids and moderate deposition (Bjornn *et al.* 1977; Gammon 1970; Hamilton 1961; Nuttall & Bielby 1973). Therefore, densities of *B. insignificans* were not expected to decrease during the silt run.

T. minutus is a sprawling mayfly on fine-coarse

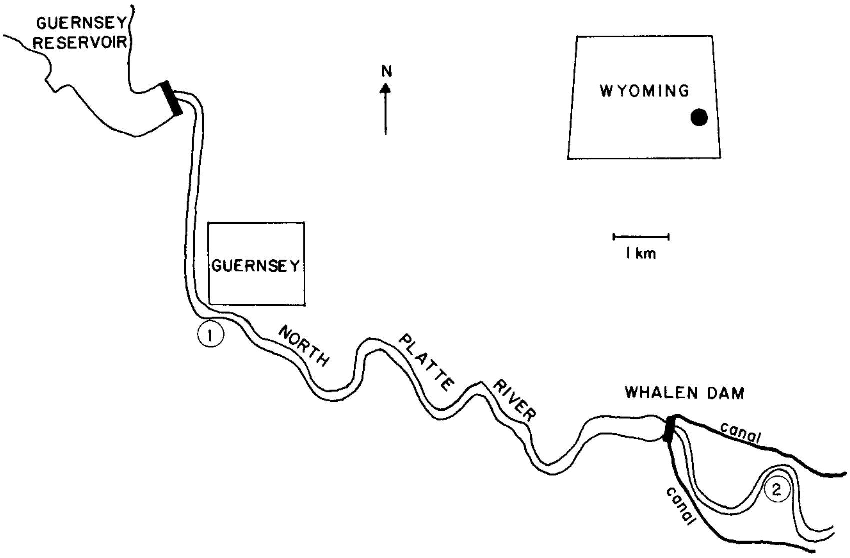

Fig. 1. Study area at Guernsey Reservoir-North Platte River, Wyoming. Circled numbers indicate sampling sites. The river is 50 100 m wide and 0.2–3.0 m deep during peak flows. Average river gradient is 1 m km^{-1}. Riparian vegetation consists of mature gallery forests and cultivated crops.

sediments. It is a characteristic mayfly of warm, turbid streams in western North America (Edmunds & Musser 1960). Gammon (1970) found that numbers of *Tricorythodes* sp. increased with high turbidities and build-up of sediments; thus, densities of *T. minutus* were expected to increase during the silt run.

Chironomids have exhibited variable responses to suspended and settled sediment. High turbidity alone may cause either a decrease, no change, or an increase in numbers (Bjornn *et al.* 1977; Gammon 1970; Hamilton 1961), although drift rates typically increase (Gammon 1970; Rosenberg & Wiens 1975). Heavy sedimentation with high turbidity may cause either decreased or increased densities (Gammon 1970; Nuttall & Bielby 1973). We expected a decrease in chironomid densities during the silt run. Although sediment deposition might eventually create favorable conditions for some species, chironomids colonizing the river in spring were more likely to be adapted to the clear flows and coarse substrates present at that time.

Populations of oligochaetes consistently increase in turbid, silted habitats (Hamilton 1961; Nuttall & Bielby 1973). Densities of these organisms were expected to increase during the silt run because of drift of organisms from Guernsey Reservoir and increases in silted substrates.

Benthic samples were collected with a modified Surber sampler that enclosed 320 cm^2 of substrate (net length = 50 cm, mesh = 0.5 mm). The sampler was secured in place with a support handle and 3-cm frame bolts. Substrate materials were either kicked or placed by hand into the net and returned to shore for elutriation. Organisms were preserved in Kahle's fluid and later transferred to ethanol for enumeration. Size classes of aquatic insects were based on measurements of total length (excluding cerci) at 10× with an ocular micrometer.

The set of environmental variables included concentration of total suspended solids (TSS) and substrate phi (ϕ) values. Phi values describe natural variation in substrate distribution caused by substrate patchiness and were expected to increase during the silt run (i.e., mean particle size decreases). TSS samples were collected with a US DH-48 sampler (U.S. Inter-Agency Committee on Water Resources 1965), filtered on Whatman® $_{GF/F}$ glass fiber filters, dried at 80°, and weighed to the nearest 0.1 mg on an analytical balance. Substrates were collected with a metal cylinder (900 cm^3) attached to a support rod. Samples were air-dried, placed on a series of standard sieves, and shaken mechanically (Ingram 1971). Mean phi values were calculated from moment statistics (McBride 1971). Average dry weight of substrate samples was 0.7 kg.

Fifteen samples were collected at each site on each date. A sample consisted of measurements of TSS concentration (taken as close to the streambed as possible), substrates (collected adjacent to Surber samples), and number of each macroinvertebrate taxon. Three random samples were taken in each of 5 locations at each site. A location was $\approx$200 m^2 of streambed from bank to thalweg in depths $>$20 cm. Locations were randomly selected on 6 July (pre-silt run) and sampled each time thereafter as a basis for temporal comparison. The 1981 silt run was conducted from 9 to 30 July. Three sets of samples were taken during the silt run (9, 16, and 23 July) and two sets were collected after (6 and 20 August).

Duplicate water samples for chemical analysis were collected in acid-washed, polyethylene bottles, transported on ice, and filtered immediately upon return to the laboratory (Whatman GF/F filters). Analyses were performed on refrigerated samples within 24 h. Nitrate-nitrogen was determined after reduction with cadmium to nitrite by a diazotization technique (Golterman *et al.* 1978). This method measures nitrate + nitrite. Soluble reactive phosphorus (SRP) was measured colorimetrically by the method of Murphy and Riley (1962). Conductivity was measured with a Hach® model 2 200 meter, pH by electrode, and alkalinity by titration with H_2SO_4. Dissolved oxygen and total sulfide samples were collected with 300-ml BOD bottles. Dissolved oxygen was determined by the Winkler method (azide modification). Total sulfide was measured idometrically after precipitation with $CdCl_2$ (Golterman *et al.* 1978).

Multivariate analysis of variance was used to test the null hypothesis of no overall change in each variable set for the period 6 July to 6 August (N = 75 per site). If the null hypothesis was rejected, then univariate tests were performed. Densities of macroinvertebrates may fluctuate from life history phenomena alone (e.g., synchronous emergence and recruitment). For example, the mayflies chosen for intensive study are known to have rapid life cycles. *T. minutus* completes larval development in 34d at 18° (Newell 1976), and *B. insignificans* has

Table 1. Physical–chemical parameters at sampling sites on the North Platte River downstream from Guernsey Reservoir, Wyoming, for the period 2 July to 20 August 1981. Upper rows are values for Site 1; lower, Site 2. Asterisks indicate silt run dates.

Parameter	2 July	6 July	9 July*	16 July*	23 July*	6 August	20 August
pH	8.25	8.33	8.30	8.13	8.28	8.30	8.15
	8.25	8.39	8.30	8.20	8.29	8.31	8.19
Conductance, μS cm^{-1}	690	820	690	780	750	700	530
	670	820	720	750	750	670	530
Total alkalinity, meq l^{-1}	2.9	2.9	3.0	2.9	2.9	2.8	2.6
	3.1	3.0	3.0	3.0	3.0	2.8	2.6
SRP, mg l^{-1}	0.01	<0.01	0.03	0.06	0.02	0.01	0.01
	0.01	<0.01	0.01	0.02	0.01	<0.01	0.01
Dissolved oxygen, mg l^{-1}	9.0	8.0	8.5	8.0	7.9	8.9	10.3
	9.0	7.9	8.1	7.6	7.9	8.8	10.4
Water temperture, °C (mean)	18.0	20.4	19.6	21.7	22.1	23.0	23.7
	18.6	22.8	19.3	21.0	22.1	22.9	23.2

several generations during summer in northwestern Colorado (Gray & Ward 1978). Thus acceptance or rejection of the null hypothesis was determined with additional information provided by size class distributions. Canonical correlations between rates of change in each set of variables were determined to further substantiate changes in biota caused by the silt run. Rates of change were calculated as the first derivative of the slope of a polynomial regression computed for each variable at each location for the period 6 July to 6 August (N = 40). This procedure eliminates within-location variation (mostly 'noise') and implies percentage rates of change that are linearly and additively related (Green 1979). All variables except substrate phi were log-transformed before analysis. Statistics were calculated with SPSS programs (Nie *et al.* 1975).

Results and discussion

The silt run had little effect on most water quality parameters (Table 1). The only chemical parameter to exhibit significant change was SRP which increased to 0.06 mg l^{-1} at Site 1. Nitrate-nitrogen was below the detection limit (0.05 mg l^{-1}). Dissolved oxygen remained high, and sulfide was not detected. Midday water temperatures were 19–23 °C throughout the study period at both sites.

Discharge from Guernsey Reservoir during the silt run varied from 109 to 150 m^3 s^{-1} with a mean of 136 m^3 s^{-1} (Fig. 2). Variations in flow did not affect sampling locations.

Concentrations of suspended solids increased 20-fold with peak values of 339 mg l^{-1} at Site 1 and 422 mg l^{-1} at Site 2 (Fig. 3). Lack of a downstream decrease in TSS indicates that materials can remain in suspension for long distances. Particle size analysis of suspended solids during past silt runs have shown that particulates are 75% silt and 25% clay (U.S. Geological Survey 1980). Because particulates remained in suspension, substrate phi values

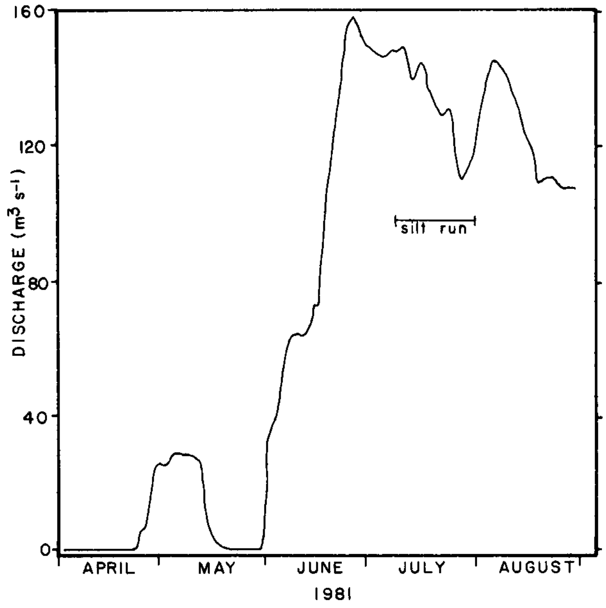

Fig. 2. Discharge from Guernsey Reservoir, Wyoming, for the period 1 April–31 August 1981. Flows depend on irrigation demand; thus, the river is dry from October to April.

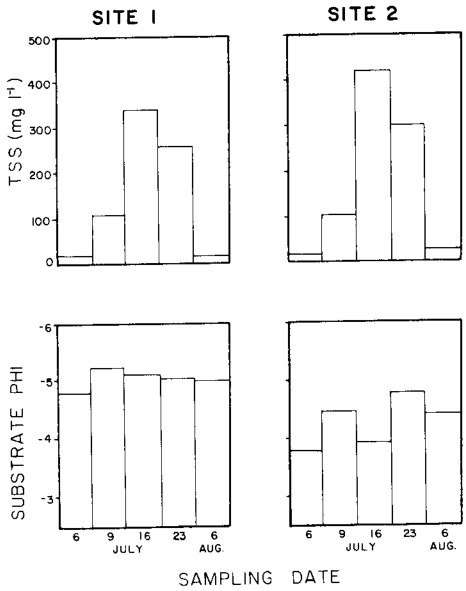

Fig. 3. Concentrations of total suspended solids and mean substrate particle size (ϕ) in the North Platte River downstream from Guernsey Reservoir, Wyoming. Overall differences in TSS and ϕ values between 6 July and 6 August were significant at both sites ($P < 0.01$), but ϕ values were not significantly different ($P = 0.49$ at Site 1, $P = 0.10$ at Site 2).

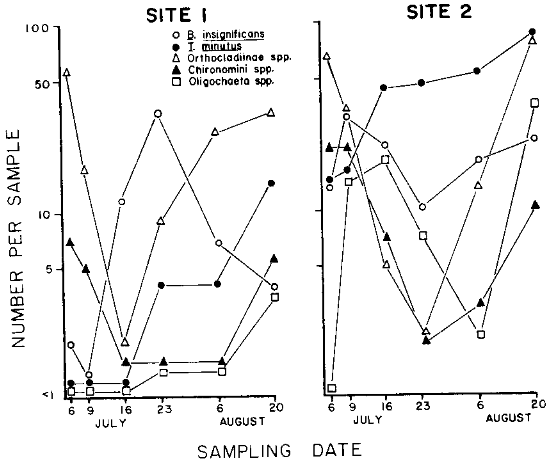

Fig. 4. Mean densities of macroinvertebrates downstream from Guernsey Reservoir, Wyoming. Overall differences in densities between 6 July and 6 August were significant at Site 1 ($P < 0.01$) and Site 2 ($P < 0.01$). Differences in densities during this period were significant for *B. insignificans* ($P < 0.01$, Site 1), *T. minutus* ($P < 0.01$, Site 1; $P < 0.01$, Site 2), Orthocladiinae spp. ($P < 0.01$, Site 1; $P < 0.01$, Site 2), Chironomini spp. ($P < 0.01$, Site 1; $P < 0.01$, Site 2), and Oligochaeta spp. ($P = 0.03$, Site 1; $P < 0.01$, Site 2). Differences were not significant for *B. insignificans* at Site 2 ($P = 0.12$).

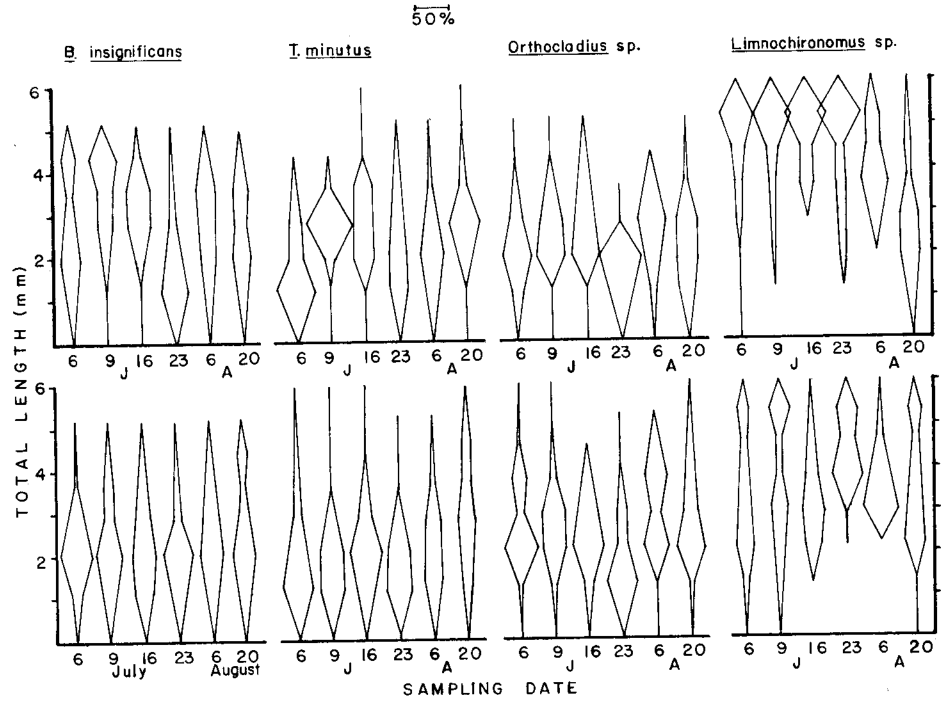

Fig. 5. Size class distributions of aquatic insects downstream from Guernsey Reservoir, Wyoming; top row, Site 1; bottom row, Site 2.

did not change (Fig. 3). Only slight deposition was observed on upper surfaces of substrates in most of the streambed. Overall, the silt-clay fraction comprised $<1\%$ of substrates. Heavy deposits (up to 3% silt-clay) were present only along shore ($<5\%$ of wetted perimeter), particularly around submerged vegetation.

Overall densities of macroinvertebrates significantly changed during the silt run at both study sites (Fig. 4). Individual taxa exhibited trends consistent with *a priori* hypotheses. Life history phenomena alone did not account for changes in densities except for mayflies at Site 1 (Fig. 5).

Densities of chironomids decreased 90%+ within 2 weeks after the silt run began. Although declines were similar for both taxa, the silt run affected different life stages. Recruitment of early instars was continuous for *Orthocladius* sp. during the silt run, but no recruitment occurred in populations of *Limnochironomus* sp. (Fig. 5). Unlike *Orthocladius* sp., *Limnochironomus* sp. constructed silk tubes throughout larval development. Suspended particulates may have interfered with feeding and respiratory mechanisms by either scouring or clogging the tubes. These effects could also explain the absence of chironomid pupae from 16 July to 23 July, because both species constructed tubes for pupation. Before and after the silt run, 5–10 pupae were collected per sample. Despite the high losses in July, densities of chironomids recovered to pre-silt run levels within 3 weeks after releases ended.

Density trends for mayflies at Site 2 followed initial predictions (Fig. 4). *T. minutus* increased from 14 individuals per sample on 6 July to 53 individuals per sample on 6 August. Densities of *B. insignificans* did not significantly change. At Site 1, densities of both species increased during the silt run, although these increases may have resulted from synchronous emergence on 9 July and subsequent recruitment during the next two weeks (Fig. 5).

Densities of oligochaetes increased at both study sites. The rapid, large increase at Site 2 at the start of the silt run suggests many organisms were derived from drift, although their point of origin is not known. Increased densities after the silt run resulted from large numbers of organisms collected in heavily-silted, shore habitats.

Elevated nutrient levels during the silt run contributed to an increase in stream algae, especially *Cladophora* (Gray & Ward 1982). Algal mats trapped some sediment, thereby providing microhabitats and food materials for many macroinvertebrates (Williams & Winget 1979).

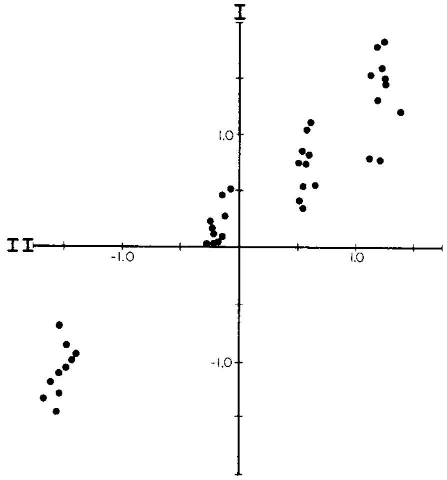

Fig. 6. Overall relationship between rates of change in densities of macroinvertebrates (Axis I) and environmental parameters (primarily total suspended solids, Axis II) during the Guernsey Reservoir silt run. Values are canonical variate scores calculated from the first correlation equation ($P < 0.01$): 0.16 Δ log *B. insignificans* + 0.06 Δ log *T. minutus* −0.70 Δ log Orthocladiinae ssp. − 0.15 Δ log Chironomini ssp. + 0.10 Δ log Oligochaeta spp. = 1.01 Δ log TSS + 0.03 Δ ϕ. Other possible correlation equations were not significant ($P = 0.94$), indicating that biotic changes mainly resulted from silt run effects. The clustering of data points are a result of similar rates of change at both study sites during each time period, e.g., cluster at top right = change at beginning of silt run, cluster at bottom left = change at end of silt run.

Overall, there was a strong correlation between changes in densities of macroinvertebrates and changes in environmental parameters (Fig. 6). Because substrates were unaltered by the silt run, nearly all of the biotic changes can be attributed to the increase in suspended solids with the possible exception of mayflies at Site 1.

The rapid response of macroinvertebrates in the North Platte River to environmental changes caused by the silt run reflects the highly perturbed conditions created by the reservoir throughout the year. Temporal contraction of stream discharge to brief periods in spring and summer combined with extreme fluctuations in releases select for species that are able to colonize and complete larval development between major disturbances (Henricson & Müller 1979). Warm stream temperatures, continuous recruitment, and rapid life cycles allow high population growth rates; thus, additional disturbance, such as the silt run, have only short-term effects on extant populations.

Summary

Increases in suspended solids caused by the flushing of sediments from Guernsey Reservoir had pronounced effects on densities of macroinvertebrates in the North Platte River. Chironomid densities greatly decreased, while densities of *T. minutus* and oligochaetes increased. Baetid mayflies are unaffected. Because flushed particulates were silt and clay that remained in suspension, changes in benthic densities occurred for many kilometers downstream. In general, the direction of change in individual populations was predictable from previous studies of sediment effects on related taxa. However, predictions of effects on some taxa, particularly chironomids, requires knowledge of past environmental conditions. The magnitude of effects and time required for recovery depend on reservoir operating procedures. In the North Platte River, sediment releases had short-term effects on benthic populations as a result of extreme annual flow variations and subsequent selection for organisms with rapid life cycles.

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