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Project Summary

An Evaluation of Environmental Stress Imposed by a Coal Ash Effluent

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Effluent discharged from the coal ash settling basin of the Columbia Electric Generating Station (Wisconsin) modified water chemistry (resulting in increased concentrations of trace metals, suspended solids and dissolved materials) and substrate quality (precipitation of a chemical floc) in the receiving stream, the ash pit drain.

A sequence of macroinvertebrate community responses to this effluent was documented: (1) decline in total abundance and taxa 4 months after effluent discharge began in 1974; (2) loss of most macroinvertebrates in 1977; and (3) recovery of the community by 1980, although a shift in dominance to more tolerant species, lower total abundance and a slight decline in diversity suggested continued sublethal influence of the coal ash effluent. The variation in the severity of stress suggested by these changes was attributable to a series of generating station activities related to coal treatment, effluent discharge characteristics, and dredging of accumulated floc in the upstream drainage ditch. The effluent response threshold (1,000 μmhos conductivity), accurately predicted the recovery of ash pit drain macroinvertebrates when effluent concentrations fell below threshold. As acute toxicity did not completely explain the reductions in macroinvertebrate abundance, we examined behavioral avoidance of modified habitats as an alternative hypothesis. Results from two studies, one a comparison of macroinvertebrate drift rates in coal ash modified and reference conditions in laboratory streams, the second, measurement of *in-situ* reponses to intermittent effluent discharge, did not support the hypothesis. However, these studies did provide evidence for sublethal effects when coal ash effluent concentrations were below the response threshold.

This Project Summary was developed by EPA's Environmental Research Laboratory, Duluth, MN, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Discharge of coal ash supernatants from wet storage ponds at coal-fired power plants can have a significant impact on aquatic ecosystems (Cherry et al. 1979, Coutant et al. 1978). Acute and sublethal impacts on aquatic organisms can occur in response to one or more of the stresses typically associated with coal ash effluent discharge: (1) the addition of elements to the ecosystem, including some potentially toxic heavy metals; (2) increases in suspended solids; (3) changes in pH and chemical balance; (4) sedimentation of chemical solids; and (5) absorption of P by fly ash interfering with nutrient cycling (Guthrie et al. 1982, Roy et al. 1981).

The Columbia Electric Generating Station near Portage, Wisconsin, consists of two coal-fired operating units, each capable of producing 527 MW per day. Fly ash from Unit I and bottom ash from both units are slurried into a series of settling basins. Following acidification, the coal ash effluent is discharged into a stream, the ash pit drain, situated in a floodplain of the Wisconsin River. This discharge

Severely modified stream habitats through precipitation of a chemical floc and increased concentrations of suspended and dissolved materials and some potentially toxic heavy metals (Magnuson et al. 1980, Andren et al. 1977). Conductivity, elevated in the coal ash effluent by adding $NaHCO_3$ to the pulverized coal, provided an easily monitored measure of effluent strength. Magnuson et al (1980) and Forbes et al. (1981) found that stream habitats receiving effluent concentrations exceeding 1,000 μmhos conductivity exhibited lower macroinvertebrate densities.

The summary incorporates results from several studies (Webster, 1983; Webster et al. 1981; Forbes et al. 1981; and Magnuson et al. 1980) to document changes in stream macroinvertebrate community structure from the pre-operation state through severe stress and later recovery. The influence of generating station activities on the severity of stress is discussed. Also presented are the results of a laboratory study investigating an alternative behavioral mechanism explaining depletion of the community by habitat avoidance through increased drift. A final study attempted to verify the laboratory drift results in the field by monitoring changes in macroinvertebrate distributions during an intermittent pattern of effluent discharge.

Materials and Methods

Behavioral Response Methods to Coal Ash Effluent

Drift Experiment

Examinations of the effects of pollution on stream macroinvertebrates have generally focused on acute toxicity. Less attention has been directed toward investigating behavioral responses to sublethal habitat modifications by pollutants. Behavioral drift has been recognized as a mechanism by which macroinvertebrates can avoid unfavorable environments (Corkum et al. 1977). Since declines in abundance and species diversity in ash pit drain habitats receiving the coal ash effluent could not be completely explained by direct toxicity, we hypothesized that the field distributions might be at least partially explained by habitat avoidance through an increased drift response.

We measured macroinvertebrate drift in plexiglas laboratory streams containing combinations of substrate and water collected from two sites, one contaminated by the coal ash effluent (APD-1) and the other an unaffected reference site in Rocky Run Creek (RRC-2) (Figure 1). A third treatment of food addition (*Acer saccharum* leaves incubated in Rocky Run Creek for 4 months) was included to investigate possible food limitation in the coal ash effluent-modified substrates.

Treatment combinations were randomly assigned to the eight laboratory streams. Substrates were added to the stream channels (11 x 52 cm) to a depth of 2 cm and the streams filled with the appropriate treatment waters to a depth of 9 cm. Shredded leaf material was partially buried at the surface of the substrates in those streams that received the food treatment. A total of 37 individuals (10 *Asellus racovitzai*, 10 *Gammarus pseudolimnaeus*, 10 Corixidae, 5 Ephemeroptera, and 2 Trichoptera) were placed in the upstream third of each stream channel and allowed to acclimate to experimental conditions without current for 2 h. After starting water circulation (generated by airstones), the drift nets at the end of each channel were emptied and drifting organisms counted after 1 h and every 3 h thereafter for 48 h. Two replicate experiments were run in March 1979 in a controlled environment room. Temperature (5.0°C) and photoperiod (12L:12D) approximated field conditions. Laboratory streams were illuminated by 15-W fluorescent lamps.

The effects of the three treatments (substrate, water and food) at two levels each on macroinvertebrate drift were analyzed using a 2^3 factorial design. Only 48 h drift data for *Asellus racovitzai* and *Gammarus pseudolimnaeus* were analyzed as the high drift rates of other taxa precluded use of ANOVA.

Substrate Choice Experiment

In August 1979, the substrate preferences of *Gammarus pseudolimnaeus* offered a choice between sediments from the coal ash effluent-modified site and from the reference site were investigated. Plexiglas chambers (30 x 16 x 11 cm) contained substrates on either side of a 2.0 cm high longitudinal divider. Twenty chambers were randomly placed in respect to a light source (15-W incandescent lamps) in a constant temperature water bath. Ten chambers received only reference substrates and served as controls. The other 10 chambers contained two substrates randomly assigned to the right or left side. On one side, 2.0 cm of reference substrate was added; on the other, ash effluent-modified substrates were layered over reference substrates. All chambers contained fresh reference site water and were aerated. Experimental conditions of temperature (22°C) and photoperiod (14L:10D) approximated ambient field conditions.

Ten *Gammarus pseudolimnaeus* were introduced into each chamber, five per side. At the end of 48 h the chamber halves were separated by a plexiglas divider and the *Gammarus* settling on each side were recovered. Data were pooled separately for treatment and for control chambers and analyzed using Chi square.

Responses to Intermittent Coal Ash Discharge

The intermittent discharge of coal ash effluent from the generating station provided an opportunity to measure macroinvertebrate responses to an abrupt change in water quality. In September 1979, we collected samples on the last 2 days of a 2-week pause in effluent discharge and on days 1, 2, 4, and 8 of discharge. Three sites were sampled: a reference site in Rocky Run Creek (RRC-2) and two modified sites, APD-1 and APD-2 (Figure 1). Triplicate samples for macroinvertebrates were collected at each site with a PONAR dredge. In addition, we measured conductance, methyl orange alkalinity, turbidity, pH, total filterable residue (TFR), current speed, water depth, and percent floc in the top 8 cm of sediment.

Multiple regression and ANOVA were used to detect significant changes in macroinvertebrate abundance related to effluent discharge. Two models were compared. Model I had independent variables for site (APD-1, APD-2 and RRC-2) and time (before and after discharge began). Model II included the above variables plus an independent variable for the site by time interaction. The model providing better fit to the dependent variable (measures of macroinvertebrate abundance and species richness) was determined by calculating the F-ratio between the regression sum of squares from the ANOVA of the two models. Two alternative hypotheses were tested: (H_0) the site by time interaction was not significant (i.e., non-significant F-ratio) and, thus, any changes in the invertebrate community following the resumption of effluent discharge could not be distinguished from natural variability exhibited at the reference site; (H_1) the site by time interaction was significant (significant F-ratio) and the changes at the experimental sites following resumption of effluent discharge were measurably different from the reference site and could be attributed to exposure to the effluent. Where F-tests were significant, a multiple comparison test identified individual sites with significant differences in before vs. after macroinvertebrate populations. This test provides 95% confidence intervals for a particular difference in means between two treatments within an ANOVA.

The dependent variables analyzed in this fashion were total macroinvertebrate abundance, Isopoda, Amphipoda and Trichoptera abundances, and number of taxa. The taxa from the three replicate PONARs were pooled for each date. Other variables were calculated as the mean from the three replicate PONARs following transformation to natural logs [$\ln(x + 1)$].

Effects on Community Structure

Magnuson et al. (1980) documented changes in macroinvertebrate community structure from the preoperation year (1974) through subsequent post-operation years (1975, 1977). We followed their methods in 1980 to determine whether recovery had taken place in response to lowered effluent concentrations. Site APD-1 (Figure 1), highly impacted by the effluent in 1977, was chosen for the 1980 study.

Two types of artificial substrate samplers were used. Basket samplers made of closed cylinders of chicken wire (20 x 30 cm) filled with 4.5 kg of limestone rock, were suspended 10 cm above stream sediments at APD-1. Macroinvertebrates were collected monthly from May through September in 1974, 1975 and 1980. A modified Hester-Dendy artificial substrate consisting of a Tuffy®* scrub pad held between two, 8-cm diameter masonite plates with an eyebolt, was used to evaluate differences between macroinvertebrate populations upstream (APD-3) and downstream (APD-1) of the effluent in June 1977 and June 1980. Samplers were suspended 20 cm over stream sediments and allowed to colonize for 1 week.

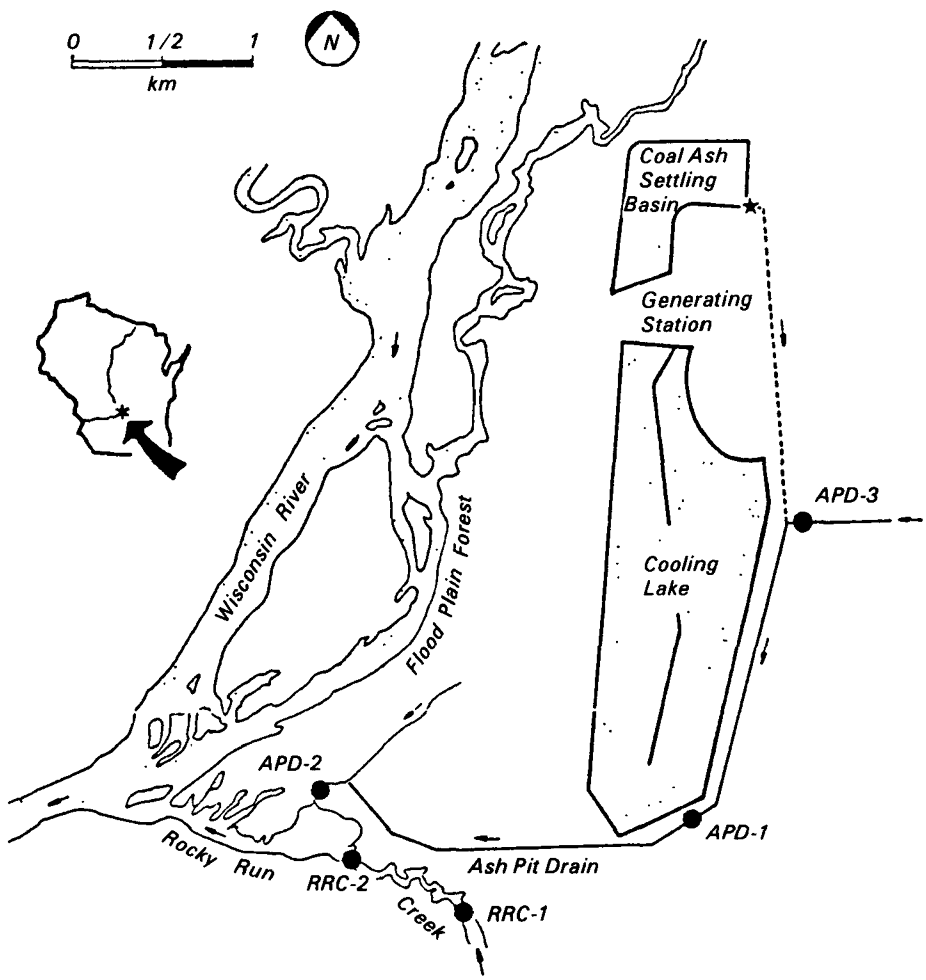

Figure 1. *Columbia Electric Generating Station study site. Sampling locations marked with closed circles. Arrows denote direction of flow. The star marks the point of coal ash effluent discharge from the settling basin into the effluent ditch (dashed line) which joins with the ash pit drain (solid line).*

Results

Behavorial Responses to Coal Ash Effluent

The hypothesis that aquatic macroinvertebrates would drift at higher rates in laboratory streams with modified conditions was not supported by the patterns of drift observed for *Gammarus* and *Asellus*. The highest drift occurred in stream chambers containing substrate and water from the reference site. *Asellus racovitzai* drifted more in response to food addition compared to no food addition and in reference substrates compared to modified substrates. The significant response to substrate should be considered as part of the substrate-water interaction. Drift was significantly higher in streams where substrate and water were from the reference site compared to all other stream chambers, while drift in streams with modified substrate and reference water was significantly lower. Except for a non-significant effect of food addition, *Gammarus pseudolimnaeus* exhibited similar responses. Drift increased in the reference substrate and the substrate-water interaction was significant. Again, the highest drift occurred in laboratory streams containing both substrate and water from the reference site.

In the substrate choice experiment, the hypothesis tested was that *Gammarus pseudolimnaeus* would display no preference for modified substrates. Chi-square analysis of data from the control chambers showed that amphipods did not discriminate between chamber sides (right vs. left or position in respect to light source) after 48 h. Likewise, no difference was observed between modified and reference substrates ($X^2 = 0.40$ for pooled data from 10 chambers).

Responses to Intermittent Coal Ash Discharge

Changes in water chemistry at the experimental sites following effluent dis-

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charge paralleled those reported in earlier studies (Magnuson et al. 1980). Conductivity, turbidity and total filterable solids (TFR) increased, while pH and alkalinity declined. Water temperature, current speed, stream depth and floc (%) in sediments did not show appreciable changes. At the reference site, stream habitat variables were relatively stable throughout the study period.

Correlations between water chemistry parameters and effluent discharge rate suggested differences in response time at the two experimental sites. At site APD-1 all the water chemistry parameters were significantly correlated with discharge rate. In contrast, at APD-2, located further downstream, only turbidity and TRF were significantly correlated with discharge rate. Other parameters (conductivity, alkalinity and pH) were more closely related to the discharge rate of the previous day. Thus, while organisms at APD-2 may have been exposed to some precursor of the effluent in the form of increased suspended material when discharge began on October 5, there was a lag of 1 day in exposure to the chemical components of the coal ash effluent. Figure 2 shows daily values for conductivity and total filterable residue at each site during the study period.

Beginning October 6, the second day of coal ash effluent discharge, macroinvertebrate abundance increased at APD-1 (Figure 2). This was due primarily to higher densities of *Asellus racovitzai* and secondarily to the amphipods *Hyallela azteca* and *Crangonyx* sp. Of the remaining 27 taxa sampled at the site, four were not collected following effluent discharge, while nine were present only after discharge began. Most of these taxa were rarely encountered; only *Phryganea* sp., *Oecetis* sp. and *Nemotelus* sp. were collected in more than three PONAR samples. In contrast to the response at APD-1, total macroinvertebrate abundance at APD-2 declined following effluent discharge (Figure 2). This decline began on October 5 when the amount of suspended material increased, but there was no chemical alteration of water quality. Decreases in densities of *Hyallela azteca* and, to a lesser extent, *Asellus racovitzai* accounted for much of the response. Of the 12 other taxa collected at this site, only *Cheumatopsyche* sp., Chironomidae and Hydroptilidae were present in three or more PONAR samples. No appreciable differences between before and after populations for these taxa were apparent. The macroinvertebrate community at the reference site, RRC-2 remained relatively stable throughout the study period (Figure 2). As at the two experimental sites, the dominant macroinvertebrates were *Asellus racovitzai* and *Hyallela azteca*. The remaining community members were comprised of 10 less common taxa.

Model II provided better fit to the total macroinvertebrate abundance, Isopoda, Amphipoda and Trichoptera data than did Model I (Table 1). The site by time interaction explained no additional variation of the number of taxa. Upon further analyses with the multiple comparison test, only a few individual site-specific changes were significant; increases at APD-1 and decreases at APD-2 in total

Table 1. *Macroinvertebrate Response to Resumption of Coal Ash Effluent Discharge*[a]

Dependent Variable	F-ratio (2,9) d.f.	Level of Significance
Total abundance	27.00	$P < 0.001$
Number of taxa	1.61	NS
Isopoda	6.53	$P < 0.05$
Amphipoda	26.69	$P < 0.001$
Trichoptera	4.93	$P < 0.05$

[a]*Given are the F-ratios, comparing the regression sum of squares from the ANOVA of the two models and the level of significance (NS = not significant) of these F ratios for five dependent variables.*

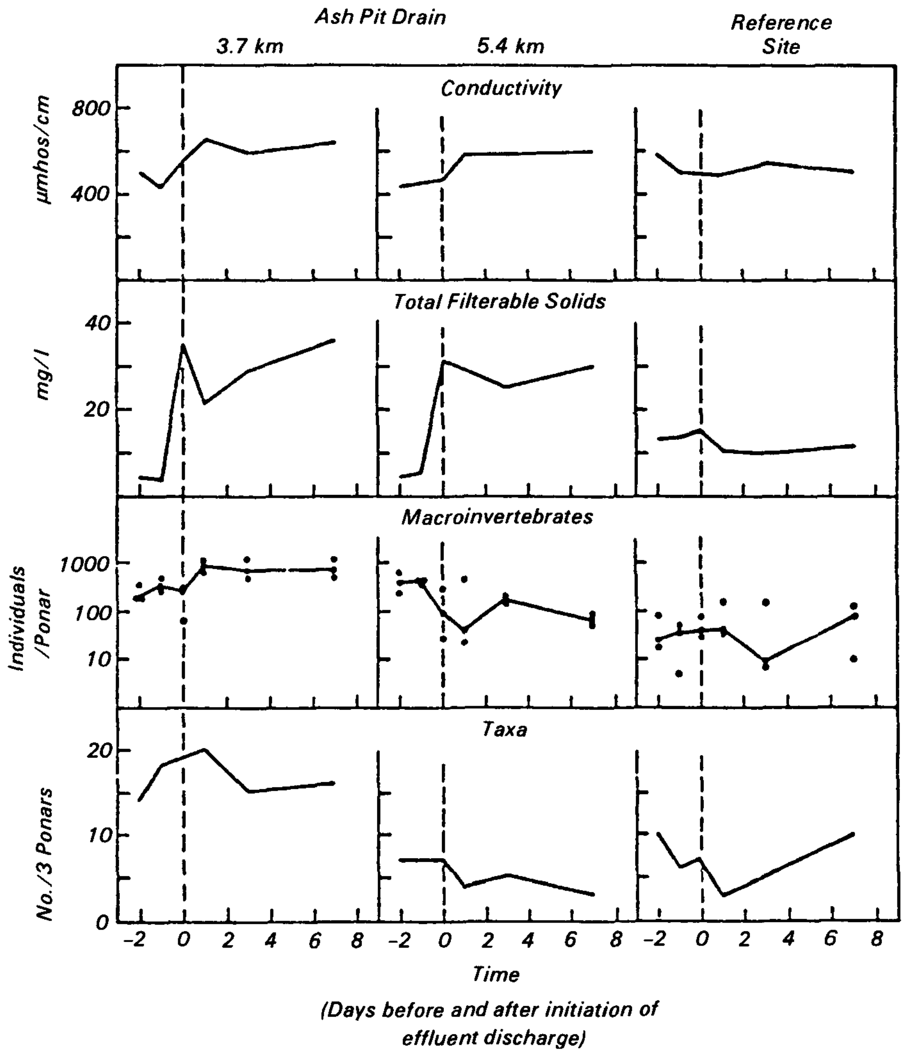

Figure 2. *Changes in conductance, total filterable solids, macroinvertebrate density and number of taxa upon resumption of coal ash effluent discharge. Ash pit drain sites 3.7 km and 5.4 km refer to APD-1 and APD-2, respectively. The vertical dashed line indicates the first day of discharge. Macroinvertebrate density (log scale) shows number of individuals in each of three basket samplers indicated by dots; the solid line connects the median. Macroinvertebrate taxa represent pooled value for three samples.*

individuals and Amphipoda abundance following effluent discharge. Although Model II provided better fit for Isopoda and Trichoptera data, variability within cells apparently masked any site-specific changes. No significant before vs. after differences were measured at RRC-2.

Effects on Community Structure

The following sequence of macroinvertebrate responses to habitat modification by the coal ash effluent was observed from colonization of artificial substrates: (1) decline in total abundance and number of taxa 4 months after effluent discharge began in 1974; (2) near disappearance of all macroinvertebrates in 1977; and (3) recovery of most taxa in 1980. The macroinvertebrate community in 1980, while similar in taxonomic composition to the 1974 pre-operation community, experienced significant shifts in absolute abundance as well as in relative abundances of individual taxa. The resulting community was characterized by lower total abundance and domination by *Asellus racovitzai*.

The shift from a community dominated by hydropsychid caddisflies in 1974-1975 to one dominated by the isopod *Asellus racovitzai* in 1980, was one of the most striking responses documented at the site. Hydropsychid caddisflies function as collector-filterers, constructing nets which retain algae, detritus, animals, and small particles carried by stream currents. The accumulation of a chemical floc coating stream substrates substantially reduced the available habitat for these caddisfly larvae and probably played an important role in their disappearance in 1977. In contrast, densities of the isopod *Asellus racovitzai* greatly increased after recovery. Numerous individuals were collected in 1979 PONAR samples and in 1980 basket samplers. Substrate modification may not have been as detrimental to *Asellus racovitzai* as the Hydropsychidae.

The comparison between colonization of substrates at the upstream (APD-3) and downstream (APD-1) sites in the ash pit drain in June 1977 and 1980, are shown in Figure 3. While there were dramatic differences between the two sites in total macroinvertebrate abundance and number of taxa in 1977, no substantial differences in these parameters were apparent in 1980.

Forbes et al. (1981) derived a biological response threshold based on effluent conductivity from a series of laboratory and field studies. Ash pit drain sites receiving concentrations of coal ash chemicals exceeding 1,000 μmhos conductance were unsuitable for macroinvertebrate colonization. As shown in Figure 3, effluent concentrations at site APD-1 in 1977 clearly exceeded the habitable limit. Conductivity was nearly 2,500 μmhos, significantly higher than the 1,000 μmhos response threshold. The lack of invertebrates mirrors the severity of environmental stress. When effluent concentrations fell below the 1,000 μmhos threshold in 1980, total abundance and number of taxa were similar to upstream values.

Discussion

Environmental stress in the coal ash drainage system of the Columbia Electric Generating Station was evaluated using a combination of biological and chemical indicators. Severly stressed sites were characterized by a substantially reduced macroinvertebrate fauna and by coal ash

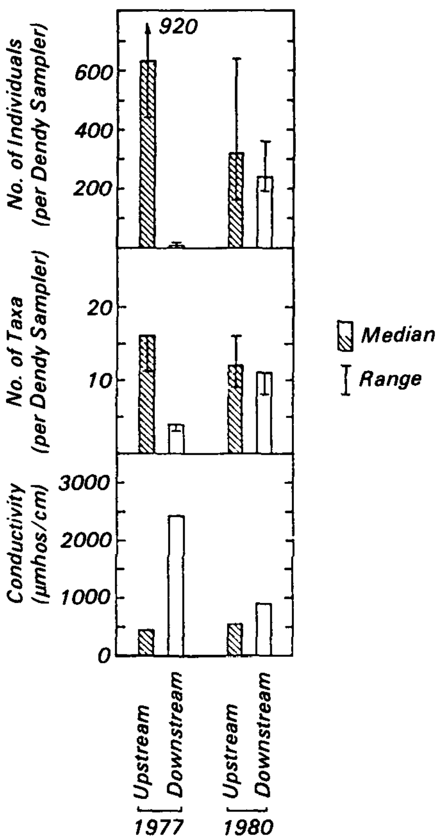

Figure 3. *Comparison between conductivity, macroinvertebrate abundance and number of taxa at upstream (APD-3) and downstream (APD-1) sites in the ash pit drain in 1977 and 1980.*

effluent concentrations exceeding the biological response threshold of 1,000 μmhos conductivity (Forbes et al. 1981). A temporal variation in the intensity of environmental stress was detected at the study site over the 7-yr study period. A partial recovery was documented 3 years after a depauperate fauna was observed.

Conductivity provided an easily monitored indicator of effluent strength within the drainage system. The major sources of conductivity in the effluent were sodium bicarbonate (1975-78) and ammonium bisulfate (1979-80) added to the pulverized coal to increase the efficiency of electrostatic precipitator operation. The transport of these compounds with the fly ash through the coal ash settling ponds and into the ash pit drain elevated conductance values in proportion to the concentration of the effluent. Thus, the main generating station activities influencing conductivity values were the frequency and rate of discharge (Table 2). The highest conductivity values (median 1805 μmhos) were measured in 1977 when discharge volume per day and the frequency of discharge were at or near peak. Only five of 25 conductivity observations made during that year were less than the 1,000 μmhos biological response threshold. By 1979 and 1980, when the frequency and rate of discharge had declined, conductivities rarely exceeded this.

The extent of floc deposits varied over the study period similar to conductivity. The thick layers of floc that accumulated on stream substrates in 1977 were substantially diminished by 1979 and were rarely observed in backwater pools in 1980. The reductions of floc formation by 1979 were associated with declines in effluent discharge (Table 2). Removal of accumulated floc in the effluent ditch immediately below the discharge point by generating station personnel also probably reduced the downstream transport of precipitated materials. The switch from H_2SO_4 addition to CO_2 bubbling for effluent pH control in 1979 may also have lessened precipitation of the dissolved metals which formed the floc.

Macroinvertebrate community structure at the ash pit drain study site reflected the severity of environmental stress predicted by the chemical indicators. In 1977 when conductivities were predominantly above threshold and floc deposits were extensive, only a few macroinvertebrates colonized artificial substrates. Both chemical and biological indicators emphasized the severely stressed conditions at site APD-1 during that year. When

Table 2. Observations of Conductivity and Extent of Floc Deposits at Site APD-1 and Generating Station Activities Potentially Influencing Ash Pit Drain Habitats. Discharge Rates are Mean Daily Discharge for Year; Conductance is Median for Year.

	Station Operations				*Indicators*	
Year	*Discharge (10^6 liter/day)*	*Coal Treatment*	*pH Control*	*Floc Removal*	*Conductance (µmhos)*	*Floc Deposits*
1975	*14*	*None*	H_2SO_4	*No*	*400*	*No observation*
1977	*19*	$NaHCO_3$	H_2SO_4	*No*	*1800*	*Extensive*
1979	*10*	NH_4HSO_4	H_2SO_4	*Yes*	*600*	*Diminished*
1980	*9*	NH_4HSO_4	CO_4	*Yes*	*500*	*Rare*

conductivities declined below threshold and floc deposits diminished in 1979-80, many macroinvertebrate taxa recolonized the previously depauperate site.

No evidence was found for behavioral avoidance of coal ash-modified habitats in the 1979 laboratory drift study or from *in situ* responses to intermittent discharge patterns. Contrary to the hypothesis that macroinvertebrates avoid habitats modified by the coal ash effluent through increased drift, the drift of *Gammarus pseudolimnaeus* and *Asellus racovitzai* was uniformly lower in laboratory streams where substrate, water, or both were from the modified site. This result suggests that these species were affected by chemical constituents of the coal ash effluent present in sediments and in the water even though concentrations were less than threshold. Habitat modifications were less severe in 1979 and the fall *in situ* study demonstrated that a community dominated by *Asellus racovitzai* and *Hyallela azteca* had recolonized the ash pit drain. The coal ash-modified habitat simulated in the laboratory streams may not have represented the severity of environmental stress that occurred in 1977 or accurately reproduced the field condition.

The reduced drift response measured in the laboratory in 1979 could have resulted from a preference for the modified over the reference conditions or from a reduction in activity in modified habitats. Preference for the modified habitat seems unlikely. When presented a choice, *Gammarus pseudolimnaeus* did not distinguish between modified and reference substrates. The coal ash effluent, which contained sublethal concentrations of several heavy metals, may have depressed the physiological activity of the stream invertebrates studied. Sublethal effects on arthropod physiology following exposure to the same effluent have been documented (Magnuson et al. 1980).

Intermittent discharge of effluent may also sublethally influence ash pit drain macroinvertebrates already acclimated to coal ash chemicals. Although responses were inconsistent, significant changes in abundance were observed at the two experimental sites. Densities increased at site APD-1 after effluent discharge resumed. This site, located below a culvert and closer to the discharge point, may have served as a refuge for invertebrates disturbed at upstream locations. In contrast, macroinvertebrate abundances decreased at site APD-2 located further downstream in a floodplain forest, a less stable habitat subject to seasonal fluctuations in water levels.

Much attention has been focused on other serious environmental problems associated with the operation of coal-fired power plants, including emissions of sulfur oxides contributing to acidic deposition, release of thermal discharges, entrainment, and chlorine toxicity. Environmentally sound disposal of two of the major byproducts of coal consumption—power plant aggregate (bottom ash and slag) and fly ash—is likely to become an equally pressing concern as the volume of waste being generated increases. Although the Federal Clean Water Act of 1977 prevents newly constructed coal-fired power plants from using wet storage of ash residues, this method of disposal was prevalent prior to passage of the Act.

Coal ash wastes have been identified as potentially hazardous pollutants due to their high suspended solids load, toxic element concentrations, and extremely acid or alkaline nature. The impacts on the aquatic ecosystems to which they are discharged can be considerable. While this and other studies demonstrate a relatively rapid recovery from a severely stressed condition, loss of sensitive species and sublethal effects may occur at lower exposure levels. The results support the need for strict control on the amount of effluent discharged into lotic environments.

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The complete report, entitled "An Evaluation of Environmental Stress Imposed by a Coal Ash Effluent: Wisconsin Power Plant Impact Study," (Order No. PB 85-213 429/AS; Cost: $10.00, subject to change) will be available only from:
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