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CYCLIC PERTURBATION OF LOWLAND RIVER CHANNELS AND ECOLOGICAL RESPONSE

F. DOUGLAS SHIELDS JR.*, SCOTT S. KNIGHT AND CHARLES M. COOPER
USDA Agricultural Research Service, National Sedimentation Laboratory, PO Box 1157, 598 McElroy Road, Oxford, MS 38655-1157, USA

ABSTRACT

Certain lowland streams have experienced prehistorical and historical cycles of aggradation, occlusion, degradation, headward incision, and renewed aggradation. Historical cycles appear to be related to human activities. A case study is presented of the Yalobusha River in Mississippi with emphasis on the effects of blockage and removal on aquatic habitats and fish. The adjacent Skuna River, which was channelized and unblocked, was used in space for time substitution to infer effects of blockage removal on the Yalobusha. Variables describing physical aquatic habitat and fish were sampled from three groups of river reaches: unblocked channelized, channelized and blocked, and naturally sinuous. Fish collections were used to compute six indicators of ecological integrity. At baseflow, mean water depths were an order of magnitude lower in the unblocked channelized stream than for the others. In-channel aquatic habitat volume per unit valley length was 5, 85, and 283 m^3/m for the channelized, blocked channelized, and natural reaches, respectively. Mean values for all six ecological indicators were lowest for the channelized group. Species richness was greatest for the channelized blocked reach. The ecological indicators displayed gradients in response to the range of observed physical conditions. Management of corridors susceptible to the cycle described above should involve a blend of measures designed to conserve higher quality habitats.

KEY WORDS: aquatic habitats; cyclic perturbation; ecological integrity; ecological response; fish; indicators; lowland rivers

INTRODUCTION

Streams draining lowland watersheds sometimes completely fill with sediment, forcing flows overbank. As explained by a Task Committee of the American Society of Civil Engineers (1971):

> This extreme condition may result from some chance obstruction, such as a log jam, or from tributary contribution of bed load which the main stream cannot carry away, or from inadequate outlet for an artificially improved channel. The term ‘valley plug’ has been used for such areas of local channel filling, with numerous bordering splay deposits, in small valleys affected by excessive channel filling from gullying of sandy upland subsoils.

Accelerated valley filling that occurred due to formation of valley plugs following European settlement has been documented for watersheds in states from Mississippi (Happ *et al*., 1940) to Texas (Jones, 1948 in Vanoni, 1975). Valley plugs, or ‘channel blocks’, have been formed in channels following deforestation and cultivation of uplands (Lowe, 1922; Little and Murphey, 1981), and at the downstream ends of straightened channels (Mississippi Board of Development, 1940; Diehl and Wolfe, 1992). In some cases, channel blockage may be due to natural causes and occur on a much larger scale. One of the most impressive cases of valley plugging occurred between ca. 1790 and 1873 on the Red River in Louisiana which affected 390–480 km of channel as well as many tributaries over a period of 375 years, forming several large lakes (Triska, 1984). Channel blocks formed by debris jams and sediments derived from upstream channel instability currently exist in Western Tennessee (Diehl, 1994) and northwestern Mississippi (Simon, 1998). Partial blocks comprised of sand are common in streams of southeastern Australia (Rutherfurd, 1996). Some evidence suggests that similar structures occurred in prehistoric times,

* Correspondence to: USDA Agricultural Research Service, National Sedimentation Laboratory, PO Box 1157, 598 McElroy Road, Oxford, MS 38655-1157, USA. E-mail: shields@sedlab.olemiss.edu

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creating extensive shallow lakes (Pflug, 1969; Saucier, 1974; Schumm *et al.*, 1981, 1984), although this hypothesis has been debated when applied to northwestern Mississippi (Grissinger and Murphey, 1983). Nevertheless, there is evidence in northwestern Mississippi lithology for a cycle of valley sedimentation–channel incision–valley sedimentation over the last 16000 years (Grissinger and Murphey, 1982, 1983). Such plugs are one type of channel obstruction that forms whenever there is a discontinuity in sediment or woody debris conveyance. Another type of obstruction is typified by large megaform bars and braided reaches that form in montane gravel-bed rivers when slugs of bed material are introduced by mass wasting, climate change, or other factors (Church and Jones 1982).

Existing literature (e.g. Vanoni, 1975) focuses on the effects of these plugs on the stratigraphic record. Happ (1968) reported that borings taken in 1937–1939 showed mean accumulations of 0.3 to 1 m of recent sediment on floodplains within 14 northwest Mississippi watersheds ranging in size from 11 to 57 km^2. Deposits were thickest in upper parts of valleys, on alluvial fans at tributary mouths, and upstream from completely filled sections of stream channels. Filled channels occurred at random locations in natural channels, near the lower ends of artificially straightened reaches (e.g. Watson *et al.*, 1997), or, in one case, upstream of a beaver dam. Channel filling forced all flow overbank, causing extensive swamping and sediment deposition on the floodplain.

Additional evidence for formation of modern channel blocks in the lower reaches of channelized streams has been derived from analysis of river stage data. A simple approach is to construct plots of annual minimum stage versus time. When coupled with a chronology of channel modifications, these plots provide a history of channel modification and response. In Figure 1, the authors have redrawn plots previously published by others for six streams in northern Mississippi. Locations of guaging stations are shown in Figure 2. Sources of data are listed in Table I. Each plot in Figure 1 shows one, two, or three abrupt drops of 1–2 m in annual minimum stage corresponding to human activities such as channelization or large-scale removal of woody debris and riparian vegetation. The decline in stage is more gradual for the Coldwater River, probably because the bed lowering was due to headward incision in response to channelization of downstream reaches rather than at the gauge site. With the exception of the Skuna River, these degradational events were followed by periods of gradually increasing annual minimum stage, with rates ranging from about 3 to 10 cm $year^{-1}$, implying a cycle period of 10–60 years. Similar patterns were reported for the Homochitto River in southwestern Mississippi, with a rate of annual minimum stage change of 4 cm $year^{-1}$ (Kesel and Yodis, 1992). These trends of increasing annual minimum stage are interpreted as evidence of system response to human disturbance (Schumm *et al.*, 1984; Harvey and Watson, 1986; Simon, 1989; Kesel and Yodis, 1992). Base level lowering by channelization results in headward incision, often by upstream progression of knickpoints and knickzones which lead to massive bank failures in upper reaches. Woody debris and sediments derived from this erosion are transported downstream to the vicinity of the gauge with resulting bed aggradation and in extreme cases such as the Yalobusha, channel blockage.

Response of fishes of the southeastern USA and their habitats to lowland river channel blockages has not been studied in a comprehensive fashion. Diehl (1994) inspected several perturbed watersheds in Western Tennessee and noted that increased flooding due to valley plugs promoted vegetational changes over extensive areas of valley bottom. Open-water communities, marshes, and wetland shrub communities were replacing bottom land hardwood swamps and croplands. Additional inferences regarding likely response of riverine systems in the southeastern USA can be drawn based on evidence regarding fish utilization of naturally occurring flooded forests (Baker *et al.*, 1991; Killgore and Baker, 1996; Light *et al.*, 1998) or river lakes and lentic backwaters (Baker *et al.*, 1991). The majority of fish species occurring in rivers of this region use seasonally flooded areas, particularly forests, for feeding, spawning, nursery areas (Killgore and Baker, 1996), refugia from high velocities (Matheney and Rabeni, 1995) or other purposes. For example, of the 91 species of freshwater fish recorded for the nontidal Apalachicola or lower Chipola Rivers, 73 are known to occur in river floodplains. Fifty-one of the 73 have been collected from the Apalachicola floodplain using limited sampling gears and approaches (Light *et al.*, 1998). Streams in this region which periodically inundate their floodplains support fish assemblages distinct from those which do not because of channel incision (Shields *et al.*, 1998).

These facts lead to the hypothesis that channel blockage is beneficial to many fish species since it produces growth in the area of permanent lentic river corridor habitats and seasonal flooded forest. A corollary to this hypothesis is that clearance of blockage is deleterious to many species when clearance transforms physical habitat conditions. This hypothesis is examined below using data describing aquatic habitat conditions and fish populations in reaches typical of rivers with blocked channels, cleared channelized rivers, and cleared natural rivers. Fish community structure is often a valuable indicator of ecosystem health in agricultural watersheds (Wichert and Rapport, 1998). The objective of this study is to develop more enlightened approaches for managing lowland riverine corridors historically subjected to cyclic perturbations. These approaches will generally involve tradeoffs between allowing natural processes

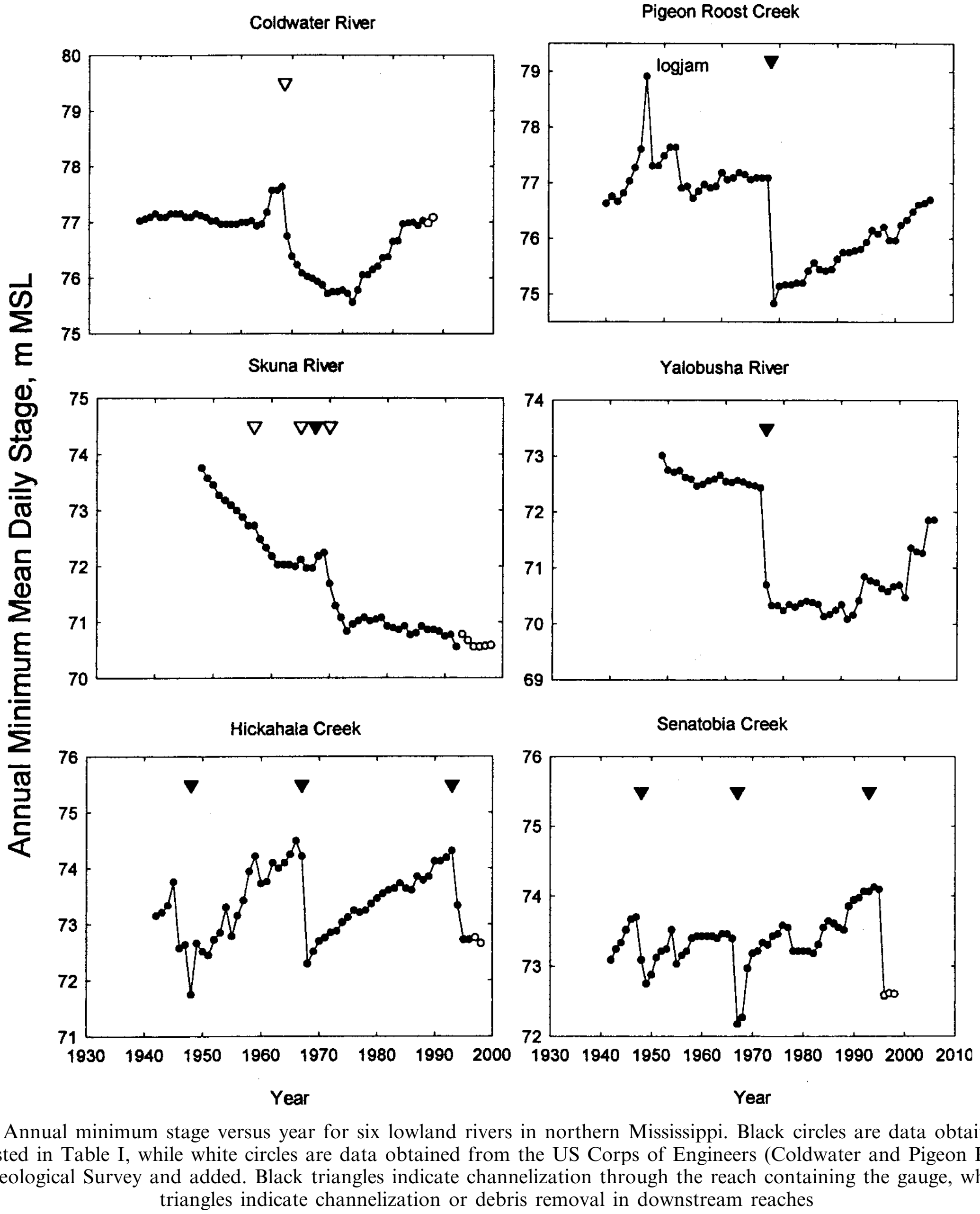


Figure 1. Annual minimum stage versus year for six lowland rivers in northern Mississippi. Black circles are data obtained from sources listed in Table I, while white circles are data obtained from the US Corps of Engineers (Coldwater and Pigeon Roost) or the US Geological Survey and added. Black triangles indicate channelization through the reach containing the gauge, while white triangles indicate channelization or debris removal in downstream reaches

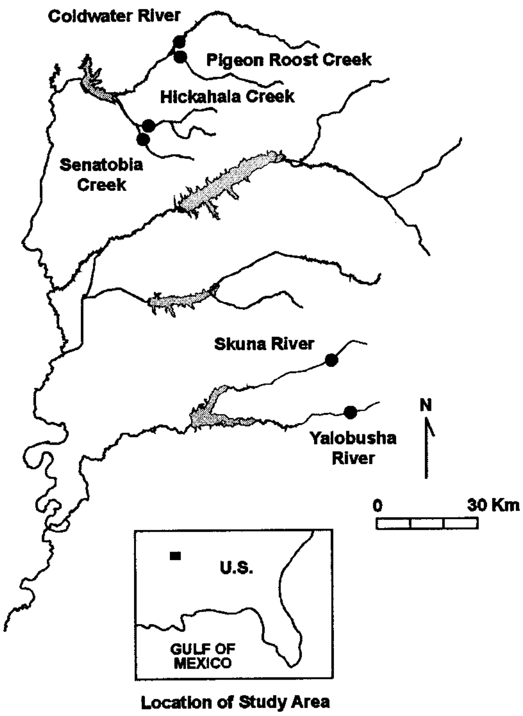


Figure 2. Location of gauges that were sources of the annual minimum stage data for Figure 1

to proceed unhindered and structural intervention. The goal is to refine knowledge regarding the relative merits of available strategies.

STUDY AREA

Two adjacent lowland river corridors in northern Mississippi with similar patterns of land use, soils, and relief but at different points within the cycle of occlusion and response were selected for study. Both are referenced in Table I and Figures 1 and 2. The Skuna River (Figure 3) is channelized and has experienced

Table I. Characteristics of streams experiencing cyclic perturbation evidenced by variations in annual minimum stage as shown in Figure 1

Stream	Contributing drainage area (km^2)	Source of data depicted in Figure 1	Remarks
Coldwater River	565	Doyle and Shields (1998)	Downstream reach channelized 1968–1969
Pigeon Roost Creek	591	Doyle and Shields (1998)	Entire contributing drainage net channelized 1920–1927 and 1968–1969
Hickahala Creek	316	Wilson (1997)	Channelized in late 1940s, late 1960s and 1992–1993
Senatobia Creek	209	Wilson (1997)	Channelized in late 1940s, late 1960s and 1992–1993
Skuna River	658	Wilson and Turnipseed (1994)	Initial channelization ca. 1925, but additional modifications in 1957 and 1965–1970
Yalobusha River	887	Simon (1998)	Initially channelized in 1910s and 1920s, additional major work in 1967

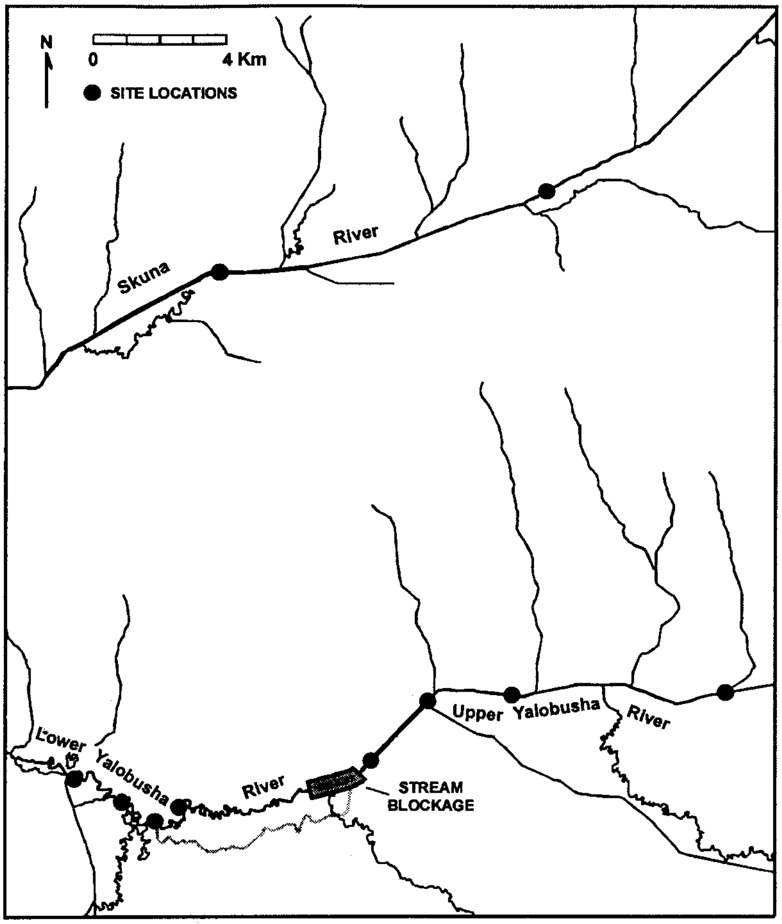


Figure 3. Location of study reaches on Skuna and Yalobusha Rivers. Reaches were 500–700-m-long segments centered on the black circles

major degradation over the last 50 years, with only one minor cycle of aggradation. Currently the channel is incised, and flow is not impeded by blockage. The Yalobusha River is presently occluded by a major blockage comprised of sediment and woody debris (Simon, 1998 and Figure 4). The river flows in a straight, trapezoidal canal (due to channelization in 1967) upstream from the block, and in a naturally sinuous channel downstream. Both rivers are tributary to the Yazoo River, which flows into the Mississippi River. Watershed relief is about 60 m. Although consolidated clays are found in deeply incised channel beds, gravel is rare and bedrock is absent. Most soils are sandy or loess. Annual rainfall within this region averages 1400 mm. About half of the land supports forests, while almost all of the remainder is cultivated, used for pasture, or idle.

In order to assess the effects of cyclic perturbation on fishes and their habitats, rivers were sampled in opposite parts of the blockage cycle (Table II and Figure 3). The Skuna River provided information regarding unblocked conditions in a channelized river, and historical information regarding physical habitat conditions for the Upper Yalobusha River prior to formation of the existing block was used to verify the suitability of the Skuna as a representative. Currently existing conditions on the Upper Yalobusha River were selected to represent a fully blocked channel. In order to provide a point of reference, the Lower Yalobusha River was also sampled as a representative of a naturally sinuous, unblocked channel.

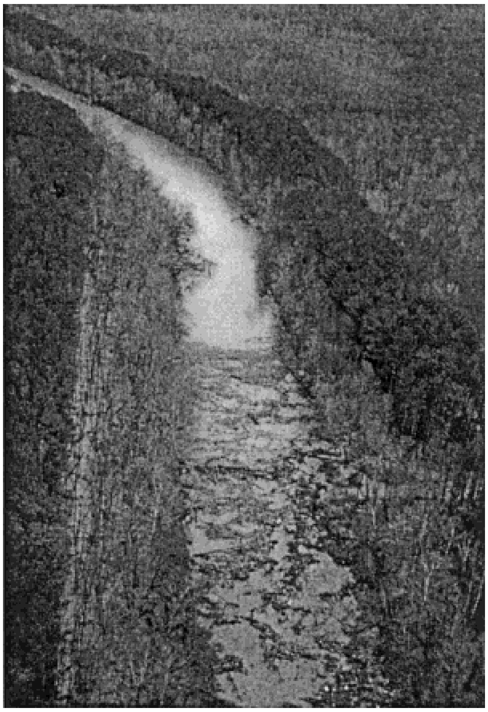


Figure 4. Upstream end of sediment and debris blockage in Yalobusha River, 1997

The blockage in the Yalobusha River formed following channelization in 1967 because the excavated channel terminated at its downstream end in a naturally sinuous meandering channel. Key characteristics of the excavated channel and the sinuous channel at their junction are shown in Table III. The thalweg was lowered as much as 1.7 m by excavation of the 1967 channel, but by 1997 as much as 6 m of deposition had occurred, creating a negative thalweg slope over a 6 km reach. Examination of repeated cross-section surveys showed that sediment plug vertical thickness increased most rapidly in the 2 years immediately after construction, and more slowly thereafter in a classical nonlinear fashion (Simon, 1998).

METHODS

The ten sites that were sampled were 500–700 m long and were distributed along about 10 km of valley bottom for each of the three river stretches (Figure 3). Differences in physical habitat quality were assessed by measuring water width, depth, velocity; and bank stability, bank vegetation type and density, woody debris density, and bed material types were visually assessed. In the Yalobusha River, an echosounder coupled with a differential global positioning system was used to obtain data for contour

Table II. Lowland rivers selected for study

River	Condition	Number of reaches sampled	Total length (m)	Sinuosity
Skuna	Channelized, unblocked	2	1000	1.0
Upper Yalobusha	Channelized, blocked	4	2700	1.0[a]
Lower Yalobusha	Natural, sinuous	4	2400	2.2[b]

[a] Three of the four reaches sampled were straight, while one had a gradual bend.
[b] Value for stretch containing the sampled reaches. Sampled reach sinuosity ranged from 1.4 to 3.5.

Table III. Hydraulic characteristics of the channelized reach of the Yalobusha River and the downstream sinuous reach at their junction ca. 1967[a]

Variable	Upper Yalobusha	Lower Yalobusha
Bankfull discharge (m^3 s^{-1})	570	70
Width (m)	52	38
Depth (m)	5.2	3
Slope	0.0005	0.0002
Sinuosity	1.0	2.2
Sediment load at bankfull (t day^{-1})	40 000	200

[a] Sediment loads estimated using the Yang (1973) approach.

maps of the study reaches. Horizontal positions were determined with RMS errors < 1.5 m. Water depths measured by the echosounder were converted to bed elevations using known or estimated water surface elevations. Digital forms of the contour maps of the sites located in the blocked reach were used to compute water volume and surface area for selected water surface elevations in order to predict the effects of blockage removal on aquatic habitat volume and area (Keckler, 1997). It was assumed that removal of the blockage from the Upper Yalobusha would decrease baseflow stages by an amount equivalent to the mean water depth observed for blocked conditions. Mean water depth was computed by dividing water volume by surface area, while mean water width was obtained by dividing water surface area by reach length. An acoustic-doppler current profiler was used to obtain detailed water velocity measurements in the upper and Lower Yalobusha River reaches for a range of low to medium discharges. Physical data were collected from Yalobusha reaches during the 2 years following fish collection. No major changes in river conditions or alignment occurred during this time.

Physical habitat data for the Skuna River sites were collected concurrently with fish. At each site, water widths were measured during baseflow at 21 transects placed at 25-m intervals. Water depths were measured at five evenly spaced points along each transect using a wading rod. Transect data were used to compute water volume and surface area using the same software package as for the Yalobusha data sets (Keckler, 1997). Discharge was measured at a selected transect using an electromagnetic velocity meter and standard techniques, and mean velocity was computed for each transect by dividing the discharge by the cross-sectional area.

In order to compare current conditions on the unblocked Skuna with historical conditions on the Yalobusha prior to block formation, discharge measurement notes were obtained from the US Geological Survey for the upper Yalobusha River. Records of baseflow water width, depth, velocity, and discharge were tabulated for a selected date for each of the years between 1973 and 1976, inclusive. This period follows channelization of the upper Yalobusha, but precedes formation of the current blockage.

To obtain an assessment of species richness and composition, fish were sampled from each site in 1997 (Yalobusha sites) and 1998 (Skuna sites). Techniques involved using backpack electroshockers for wadeable sites (Skuna) and boat-mounted electroshockers for deeper waters (Yalobusha). Hoop nets and seines were also employed in the deeper waters.

For data analysis, all captures were lumped together regardless of gear type. Although the authors are aware of the problems presented by gear bias, the analysis is based on species presence and absence and does not utilize species relative abundance, which is less sensitive to environmental perturbation than metrics based on species number (Paller, 1996). Therefore it was appropriate to compile species lists obtained by using a mix of gear types appropriate to the sampled habitats (Fago, 1998; Wichert and Rapport, 1998).

Fish species lists were used to compute six quantities proposed by Wichert and Rapport (1998) as indicators of ecological integrity in agricultural watersheds drained by warmwater streams. Following Wichert and Rapport (1998), first, integer scores were assigned to each fish species captured, based upon habitat orientation and feeding group in such a way that a higher scores were associated with greater sensitivity to ecosystem stress (Table IV). Then values of the first five indicators shown as columns in Table IV were computed for each site and for each river as follows:

Table IV. Estimates[a] for characteristics of fishes of the Yalobusha and Skuna Rivers

Family	Species	Age at maturity (year)	Maximum size (mm)	Habitat orientation[b]	Habitat flow preference[c]	Feeding group, trophic level[d]
Amiidae	*Amia calva*	II[f]	610	2	2	5
Aphredoderus	*Aphredoderus sayanus*	II[i]	144	2	2	3
Atherinidae	*Labidesthes sicculus*	II[f]	100	4	2	3
Catostomidae	*Ictiobus bubalus*	III[g]	890	3[f]	1	4
	Ictiobus cyprinellus	III[g]	890	3	2[f]	6[f]
	Minytrema melanops	I to II[g]	460	3	2	4
Centrarchidae	*Lepomis cyanellus*	I	200[k]	3[k]	2	4[k]
	Lepomis gulosus	I[h]	203	4	2	3[i]
	Lepomis humilis	II[h]	102	2	2[e]	3
	Lepomis macrochirus	I[g]	256	4[c]	2	3[k]
	Lepomis megalotis	I[h]	178	4	1	3[i]
	Lepomis microlophus	I[h]	279	4	2	4[i]
	Micropterus punctulatus	I[i]	432	2	1	5[i]
	Micropterus salmoides	II[i]	762[h]	2[h]	2[h]	5[h]
	Pomoxis annularis	II	508	4	2	5
	Pomoxis nigromaculatus	I[h]	460	4	2	5[i]
Clupeidae	*Dorosoma cepedianum*	II[l]	520[f]	5	2	6[f]
Cyprinidae	*Cyprinella venusta*	I[f]	128[f]	4[f]	1[f]	4[f]
	Cyprinella camura	I[f]	114[e]	4[e]	1[e]	3[f]
	Cyprinus carpio	III[f]	700[f]	3	3	1[f]
	Lythrurus fumeus	I	66[f]	5	2[f]	4
	Lythrurus umbratilis	I	81[f]	5[e]	2[e]	4[f]
	Notropis atherinoides	I	124[e]	5[f]	3[f]	3
	Notropis buchanani	I	50	3	2	1
	Notropis rafinesquei	I[i]	45[i]	3[i]	1[i]	4[i]
	Opsopoeodus emiliae	I	65	4[f]	2	1
	Pimephales notatus	I[i]	110[f]	3[i]	1	4[f]
	Pimephales vigilax	II[f]	92[f]	3[i]	1	1
Esocidae	*Esox americanus*	I[l]	380[m]	2[f]	3[f]	5[f]
Fundulidae	*Fundulus notatus*	I	74	1	2	3
	Fundulus olivaceus	I	97	1	2	3
Ictaluridae	*Ameiurus natalis*	II[g]	380	3	2	1
	Ictalurus furcatus	I[g]	1550[f]	3	1	1
	Ictalurus punctatus	I[g]	540[f]	3[i]	3[i]	1[i]
	Pylodictis olivaris	IV[g]	985[f]	3	2[i]	5
Lepisosteidae	*Lepisosteus oculatus*	II m III f[i]	1120[f]	2[f]	2[f]	5[f]
	Lepisosteus osseus	III m VI f[e]	1830[f]	4	3[f]	5[f]
	Lepisosteus platostomus	III[l]	800[f]	5[f]	1[f]	5[f]
Moronidae	*Morone chrysops*	II	380	5	3	5
Percidae	*Percina sciera*	I[j]	110	3[j]	1[10]	4[j]
Poeciliidae	*Gambusia affinis*	II[g]	55	1	2	3
Sciaenidae	*Aplodinotus grunniens*	III	711	5	2	4

[a] Based on Mettee *et al.* (1996) except where noted otherwise.
[b] 1 = surface; 2 = littoral or vegetation; 3 = benthic; 4 = general; and 5 = pelagic.
[c] 1 = lotic; 2 = lentic; 3 = both lotic and lentic.
[d] 1 = omnivore; 2 = herbivore; 3 = general invertebrates; 4 = benthic invertebrates; 5 = fish and large invertebrates; and 6 = plankton and microcrustaceans.
[e] Pfleiger (1975).
[f] Etnier and Starnes (1993).
[g] Carlander (1969).
[h] Carlander (1977).
[i] Personal observation, S.S. Knight.
[j] Kuehne and Barbour (1983).
[k] Scott and Crossman (1973) in Wichert and Rapport (1998).
[l] Wallus *et al.* (1990).
[m] Trautman (1981).

$$\mathrm{SACS}_j = \frac{\sum_{i=1}^{N} \mathrm{SCS}_{ij}}{N},$$

where SACS = species association characteristic score j; SCS_{ij} = value of indicator j for species i as shown in Table IV; and N = number of species. When different values occurred for the age at maturity for males and females, the average value was used in analysis. The number of species constituted the sixth indicator. Relationships among the indicators and physical habitat metrics were examined.

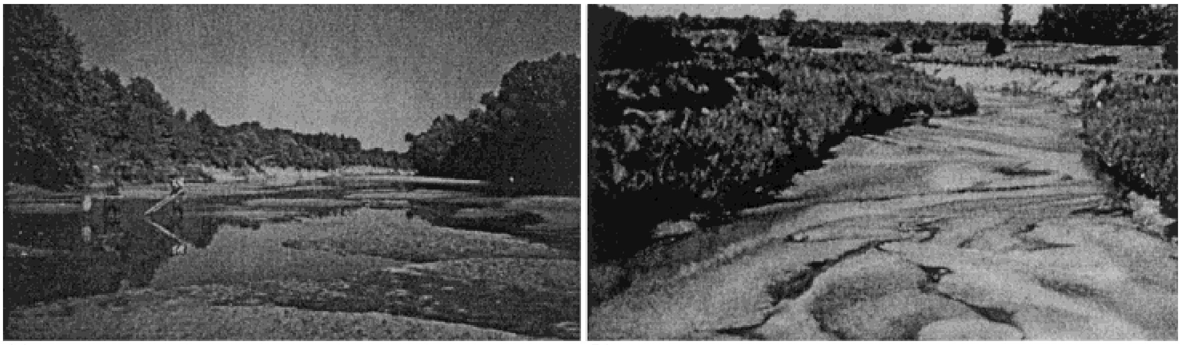
RESULTS

Physical habitat—qualitative

The unblocked, channelized Skuna sites were flanked by bare, near vertical banks 5–8 m high crowned with mature trees. Since top bank widths were approximately 60 m, canopy over the water surface was minimal. Beds were comprised primarily of shifting sand with some consolidated clay outcrops. Large woody debris was present, but scarce, with a horizontal surface density of less than 30 m^2 ha^{-1} water surface. A buffer of forest up to 50 m wide separated the channel from cultivated fields. Current photographs of the Skuna resemble photographs of the Yalobusha taken prior to formation of the existing channel blockage (Figure 5).

The blocked channel was straight, trapezoidal, and quite wide. Sand waves (dunes) were observed on the echosounder screen, and some submerged woody debris. Submerged and emergent woody debris became more common closer to the upstream face of the blockage. Banks were stable except for occasional rotational failures, and covered with deciduous pioneer species (*Salix* sp., *Betula nigra*, *Platanus occidentalis*) at lower levels. Embankments of excavated material about 5–10 m high were located within 20 m of top banks, and the crowns of these banks were covered with pines (*Pinus* sp.) evidently planted about the time of channel construction (1967). Repeated observations indicated that the blocked channel hydraulically resembled a lake with a broad spillway, and water surface elevation varied little with discharge. As discharge increased, water flowed out of the channel through relief openings in the embankments and flowed across the forested floodplain. On the southern floodplain, overflows found their way into an abandoned channel and made their way to the Lower Yalobusha. The course of this channel was mapped using a Global Positioning System (Figure 3).

Although Lower Yalobusha River mapping was confined to the sinuous main channel, water covered the floodplain on both sides of the channel for an indeterminate distance. The top bank was underwater, but its approximate location was clearly marked by a dense growth of woody vegetation that bordered the channel on both banks. Woody debris was common if not abundant, and there were numerous



(a) (b)

Figure 5. Conditions in channelized streams during unblocked segment of cycle. (a) Skuna River, 1998. (b) Upper Yalobusha River, 1972

baldcypress trees (*Taxodium distichum*) within and adjacent to the channel. Submerged woody debris was often observed on the echosounder screen. Variation of water depth laterally and longitudinally was relatively slight.

Physical habitat—quantitative

Summary statistics for physical habitat measurements highlight the radical differences in the three channel conditions (Table V). Measurements in the Skuna River appear typical of observations for the Upper Yalobusha prior to blockage. Investigators who sampled the Upper Yalobusha study reach in 1973–1976 described habitat as a riffle–shallow pool combination (Cooper and Johnson, 1980). Bed materials were mainly sand and gravel with some clay and silt deposits in pools. Water depths ranged from 0.05 to 0.2 m in riffles and 0.5 to 1.5 m in pools. Velocities at low flow were described as 'sluggish'. Stream gauging measurements made in the Upper Yalobusha during the same period indicated that cross-sectional mean water depths were 0.08–0.11 m and current velocities were between 9 and 50 cm s^{-1} when discharges were in the range of 0.1–0.3 m^3 s^{-1}. Cross-sectional mean water depths were observed from 0.03 to 0.59 m and cross-sectional mean current velocities between 2 and 54 cm s^{-1} in the Skuna when discharges were 0.3–0.7 m^3 s^{-1}.

Contour maps and cross-section plots revealed that the channelized, blocked reach (Upper Yalobusha) was geometrically less complex than the sinuous natural reach downstream (Lower Yalobusha) (Figures 6 and 7). Despite the effects of blockage on the Upper Yalobusha, water depths were greater in the natural reach downstream (Table V). Greater depths and sinuosity in the Lower Yalobusha produced higher values of aquatic habitat area (1.7 ×) and volume (3.3 ×) per unit downvalley distance than for the wider, straighter, shallower blocked channel upstream (Table VI). Aquatic habitat volume for the Skuna was about two orders of magnitude smaller than for the other reaches, and predicted values for the Yalobusha following blockage removal were similar to those for the Skuna.

Typical velocity fields for the Upper and Lower Yalobusha measured using the acoustic doppler current profiler are shown in Figure 8. The data shown in Figure 8 were collected at discharges of 20.4 and 23.5 m^3 s^{-1} for the Upper and Lower Yalobusha, respectively. This level of flow is exceeded about 25% of the time in the Upper Yalobusha (Simon, 1998). Figure 8 emphasizes the low-velocity, depositional nature of upstream reaches, and the nearly lentic habitat they provide. In contrast, reaches downstream are more riverine, with turbulence related to the strong secondary circulation typical of a meandering channel.

Table V. Aquatic habitat quality in Yalobusha and Skuna Rivers at baseflow

River	Condition	Mean water width (m)	Mean water depth (m)	Cross-sectional mean water velocity (cm s^{-1})	Substrate	Discharge range for observations (m^3 s^{-1})
Skuna	Channelized, unblocked	24	0.2	19	93% sand	0.3–0.7
Upper Yalobusha	Channelized, blocked	48	1.7	7–21	Sand and woody debris. Local deposits of silty mud and clay	11–28
Lower Yalobusha	Natural, sinuous	38	3.5	2–120	Unknown—but almost certainly sand in view of velocities observed and upstream geology	2–63

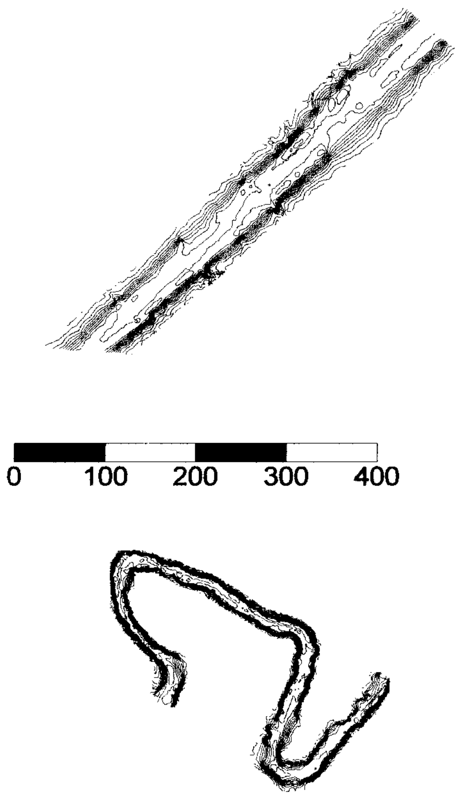


Figure 6. Contour maps of the beds of typical reaches of the Upper Yalobusha (top) and Lower Yalobusha (bottom) River

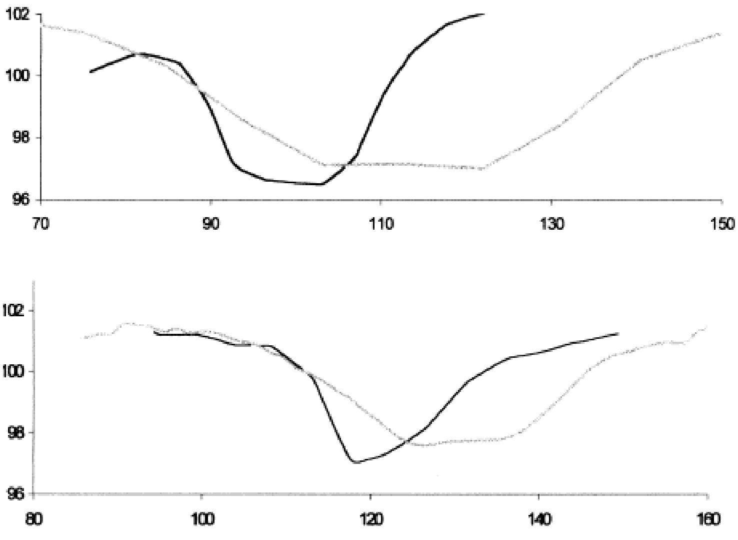


Figure 7. Typical cross sections for reaches of the Upper (heavy gray line) and Lower (light black line) Yalobusha Rivers

Table VI. Quantitative aquatic habitat conditions in Yalobusha and Skuna Rivers

River	Condition	Channel water surface area per meter of downvalley distance (m)	Channel water volume area per meter of downvalley distance (m^2)
Skuna	Channelized, unblocked	26	5
Upper Yalobusha	Channelized, blocked	49	85
Lower Yalobusha	Natural, sinuous	84	283
Upper Yalobusha	Predicted conditions following removal of blockage	16	8

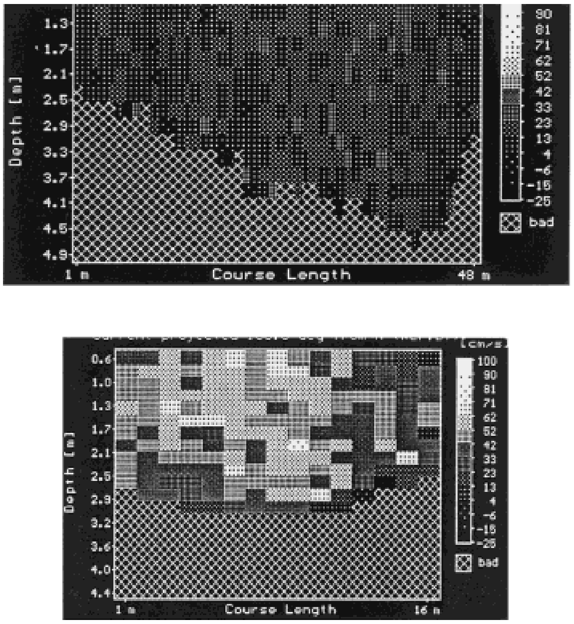


Figure 8. Velocity distributions for cross sections of the Upper Yalobusha (top) and Lower Yalobusha (bottom) River. Velocity is projected in the direction of the channel centerline. Figures shown are screen dumps from the TRANSECT program. Reproduced by permission of RD Instruments, San Diego, CA

Fish

A list of fishes captured for this study is presented in Table VII. The natural reach and the unblocked, channelized reach yielded only 18 and 17 species, respectively, while 31 species were captured within the blocked, channelized reach. The natural, blocked, and unblocked reaches yielded an average of 9.25, 17.25, and 13.5 species per sampled site, respectively. Species richness was greatest for the two sites immediately upstream from the sediment and debris jam, perhaps due to the high levels of woody debris, greater depths, and moderate levels of disturbance there relative to other reaches.

SACS values for each river computed as described above are presented in Table VIII. All six indicators were lowest for the channelized, unblocked Skuna, and all indicators except number of species were greatest for the naturally sinuous Lower Yalobusha. The blocked canal (Upper Yalobusha) yielded intermediate values for all indicators except for number of species.

With the exception of number of species, SACS indicators computed for each of the ten sites were correlated with descriptors of physical habitat (e.g. mean depth). For example, variation in mean depth

Table VII. Fish collections from Yalobusha and Skuna Rivers

Family	Species	Lower Yalobusha	Skuna	Upper Yalobusha
Amiidae	*Amia calva*			1
Aphredoderus	*Aphredoderus sayanus*		1	
Atherinidae	*Labidesthes sicculus*			5
Catostomidae	*Ictiobus bubalus*	419	1	35
	Ictiobus cyprinellus	2		49
	Minytrema melanops			1
Centrarchidae	*Lepomis cyanellus*		11	3
	Lepomis gulosus	1	2	2
	Lepomis humilis			4
	Lepomis macrochirus		171	29
	Lepomis megalotis		14	
	Lepomis microlophus			3
	Micropterus punctulatus	1		
	Micropterus salmoides		7	
	Pomoxis annularis	1		4
	Pomoxis nigromaculatus	2		1
Clupeidae	*Dorosoma cepedianum*	4		38
Cyprinidae	*Cyprinella venusta*	3	640	90
	Cyprinella camura		1	
	Cyprinus carpio	18		38
	Lythrurus fumeus			12
	Lythrurus umbratilis			52
	Notropis atherinoides	25		18
	Notropis buchanani			1
	Notropis rafinesquei		128	
	Opsopoeodus emiliae			1
	Pimephales notatus			1
	Pimephales vigilax		8	5
Esocidae	*Esox americanus*			3
Fundulidae	*Fundulus notatus*		5	
	Fundulus olivaceus	1		
Ictaluridae	*Ameiurus natalis*			3
	Ictalurus furcatus			2
	Ictalurus punctatus	9	18	37
	Pylodictis olivaris	13	1	5
Lepisosteidae	*Lepisosteus oculatus*	6	9	19
	Lepisosteus osseus	3		39
	Lepisosteus platostomus	6		
Moronidae	*Morone chrysops*	5		
Percidae	*Percina sciera*		1	
Poeciliidae	*Gambusia affinis*		104	2
Sciaenidae	*Aplodinotus grunniens*	3		2
	Totals	522	1122	505

and in the area of aquatic habitat per unit valley length explained 87% and 49%, respectively, of the variation in maximum fish size. Many of the SACS were also correlated with one another, which confirms findings by Wichert and Rapport (1998). The intercorrelation of many of the indicators evidently shows that they are linked to a suite of ecosystem responses to physical stress. To display the ecological response to the observed physical habitat gradients, two of the SACS indicators were selected that were free of significant intercorrelation ($r^2 < 0.32$, $p > 0.05$), and plotted against two uncorrelated variables that were descriptive of key habitat conditions (Figure 9). A gradient of ecological indicators occurred in response to the range of physical conditions that occurred moving from the unblocked, channelized river, through the blocked channel and was greatest for the naturally sinuous reach. Fishes preferring pelagic or benthic

Table VIII. Species association characteristic scores based on fish collections from Yalobusha and Skuna Rivers

River	Condition	Age at maturity (year)	Maximum size (mm)	Habitat orientation	Habitat flow preference	Feeding group, trophic level	Number of species
Skuna	Channelized, unblocked	1.6	347	2.8	1.6	3.4	17
Upper Yalobusha	Channelized, blocked	1.8	466	3.4	2.0	3.5	31
Lower Yalobusha	Natural, sinuous	2.2	629	3.6	2.1	4.2	18

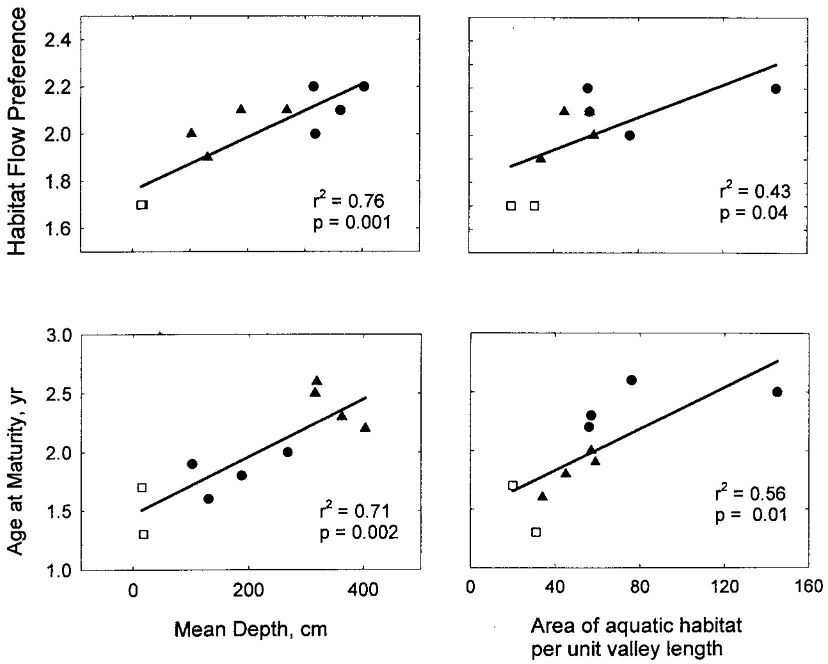


Figure 9. Plots of selected SACS for each of the ten sampled sites (Figure 3) versus selected descriptors of physical habitat. Open squares represent Skuna River (channelized, unblocked), black triangles represent Upper Yalobusha River (channelized, blocked), and black circles represent Lower Yalobusha River (natural, sinuous). Lines are ordinary least-squares regression lines, and coefficients of determination (r^2) and associated probability values are from the regression

habitats were common in deeper waters, while the shallow unblocked channel was dominated by those preferring surface and littoral habitats. Species capable of attaining larger sizes preferred deeper waters and were most common in the sinuous Lower Yalobusha, which offered greater depth and habitat quantity per unit valley length. Species richness was relatively insensitive to the observed range of water depth, width, and habitat quantity. Evidently the relatively diverse fauna typical of the unblocked, channelized Skuna and similar habitats in this region (Paller, 1994; Shields *et al.*, 1995) compensated for the absence of many of the larger species found in the natural Lower Yalobusha (Table VII).

DISCUSSION

The metrics devised by Wichert and Rapport (1998) and adapted for use here were highly correlated with physical variables in a fashion that the authors judge as reflective of ecological response to physical stresses (Figure 9). The formulation of these indicators may be criticized because they are based on the arithmetic mean of certain discrete and continuous variables, and therefore return the same value for associations comprised of one or a few species with values that cluster about the mean and for associations with extreme values that have the same mean. However, warmwater fish communities tend to respond to physical habitat degradation associated with channelization and erosion in ways outlined by Schlosser (1987) that are well documented by means of the selected characteristics. The ecological mechanisms responsible have been well described by Schlosser (1987), Wichert and Rapport (1998), and others, and thus are not repeated here. The authors' application of the work of Wichert and Rapport (1998) may be more specifically criticized in that the metrics were used for spatial rather than temporal comparisons and that a relatively modest number of fish samples were used. Although more data are almost always desirable, the spatial differences observed are striking enough to at least provide a caution to those responsible for manipulating these systems. Without time travel machines, spatial comparisons are often required to generate prediction. The indicators were used to digest the data from the fish samples, not to create results.

Lowland river corridors susceptible to blockage via valley plug formation present a vexing problem for managers. Too often choices are made that maintain a cycle of disturbance that requires costly maintenance and result in environmental degradation. These choices are not made entirely through ignorance. Four decades ago, it was noted by Miller (1960):

> . . . in channel straightening where the slope is increased significantly it is easy to create upstream problems because of induced degradation and downstream problems because of aggradation and increased flood impact by more efficient transfer of water (and sediment) from above to below an altered reach.

Evidently economic forces and political expedience often dictate what must be done. Diehl (1994) identified five types of strategies available for responding to lowland river blockage by valley plug formation (Table IX). It would seem that the best solution in most cases would be a mix of these five strategies. In any case, a pivotal issue will always be matching sediment supply and transport capacity. For example, channel excavation, if applied alone, will temporarily relieve flooding and accelerated sedimentation immediately upstream from the block, but will likely rejuvenate incised reaches upstream, thus repeating the cycle of perturbation depicted in Figure 1. On the other hand, if grade-control structures are used to reduce erosion in the watershed upstream from the block, these must be designed to create and maintain a balance between flow energy and sediment supply balance. In some cases, downstream degradation followed construction of grade-control structures, thereby destabilizing channel banks (Simon and Darby, 1997). In addition, sediment control structures employed throughout the watershed may not impact sediment load downstream for many decades due to lagging fluvial response (Trimble, 1975; Trimble and Lund, 1982).

Schemes which feature forced deposition of sediments in a transition zone between upstream sediment sources and the sink area produced by the plug may provide opportunity for floodplain habitat rehabilitation, particularly if coupled with restoration of a naturally sinuous channel through or around the plug. As noted by Miller (1960):

> The desirable procedure is to design a sinuous channel. . . wherein a slope between two control points is established that is compatible with the sediment load and the channel design shape thereby minimizing any upstream effects and grade control requirements.

Sinuous channels offer additional benefits in terms of ecological function, since habitat depth and velocity distributions tend to be less uniform in meandering channels, and physical habitat diversity is an indicator of fish habitat values (Gorman and Karr, 1978; Schlosser, 1987). Some evidence suggests rivers with complex cross-sections including shelf-like features are more retentive of organic matter than more uniform channels (Thoms and Sheldon, 1996). The variance of depth has been correlated with the number

Table IX. Alternative strategies for managing lowland river corridors blocked by valley plugs (Diehl, 1994)

Alternative	Advantages	Disadvantages
Channel excavation	The channel can be straight or sinuous: it can follow a new alignment or the existing channel. Provides the best likelihood for locally increasing the areas available for profitable agriculture and forestry	Channel might need dredging periodically to maintain channel capacity. Can lead to upstream degradation and widening, and increase the amount of sediment entering the excavated reach
Removal of woody debris	Less disturbance to the environment and lower cost than excavation	Removal of fish and invertebrate habitat. Less effective than excavation in reducing flooding and sedimentation
Forced deposition of sediment in selected areas	Sediment deposition upstream can reduce the potential for valley plug formation in downstream reaches	Difficult to design and locate depositional areas that retain the right quantities of sediment
Erosion reduction in the watershed upstream from the blockage, particularly from gullies and low-order tributaries	Erosion control across the watershed treats one of the primary causes of the problem and offers greatest likelihood of sustainability	Sediment sources are extremely diffuse, and cost of structural control for a significant fraction may be prohibitive
Adaptation to existing conditions by changing land use patterns and objectives	Reduced need for construction projects. Preservation of habitats created by valley plug and channel blockage	Significant expenditures may be required for land and easement purchases and subsidies. Removal of land from production may be politically unpopular

and diversity of fish species richness in a restored river (Jungwirth *et al.*, 1993, 1995). The results suggest that simply clearing the channel obstruction and restoring an unblocked, channelized regime is detrimental to ecosystem integrity. The ecological indicators computed from fish species composition suggest that the unblocked, channelized condition represents a state of greater distress (Rapport *et al.*, 1985) than the blocked condition, which may be thought of as a first step in natural recovery to the disturbance of channelization and attendant channel incision. Clearly, under either natural conditions or those created by human disturbances, the habitats created by channel occlusion and valley plugging are temporally unstable relative to those found in the natural meandering reach.

An optimal solution to the problem of channel blockage might include sediment control structures in watershed headwaters, sediment storage in channels enlarged by erosion or channelization, and creation of a meandering channel within an enlarged floodway around the channel blockage. The enlarged floodway could be used for sediment storage. Project maintenance might include periodic removal of sediment from storage areas. Sediments could be used to develop upland habitats, ridge-and-swale floodplain topography, or for construction of levee embankments to confine flooding to the designated floodway.

CONCLUSIONS

Historical approaches to watershed management have led to an acceleration of a natural cycle involving formation of valley plugs, breaching or local destruction of the plugs, and headward incision leading to generation of sediment and debris that occlude channels and form new plugs. Despite the technological advances of recent decades, strategies adopted for managing disturbed watersheds often lead to headward erosion and formation of channel blocks or valley plugs. Removal of blocks or breaching plugs triggers a new wave of headward erosion, generating excess sediments which deposit to form a new block. This cycle may be broken by adapting land use objectives and policies to the hydrologic regime created by the channel blockage or by a variety of structural approaches. The best approach for a given watershed is likely to be a mix of channel clearing, channel construction, upstream erosion controls, and forced deposition of sediment in designated storage zones.

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