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ENVIRONMENTAL IMPACT OF STREAM CHANNELIZATION[1]

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ABSTRACT: Geologic, engineering, and biological investigations of six Pennsylvania coldwater streams were undertaken to determine the impact of channel modifications instituted both prior to and following Hurricane Agnes. The primary focus of the study was on the ecological changes brought about by stream channelization.

No long-term deleterious effects on water quality, attached algae, benthic fauna, or forage fish populations were found. Trout, however, were found to be greater in numbers and weight in natural than in channelized stream reaches. Lack of suitable physical habitat appears to be the primary cause of reduced trout populations in stream reaches which have been channelized. (KEY WORDS: channel improvements; trout; benthos; water quality; hydrology; freshwater fishes; Hurricane Agnes.)

INTRODUCTION

During June of 1972 Hurricane Agnes moved in an erratic pattern through the State of Pennsylvania. Total precipitation received during the 5-day storm period ranged from four to 18 inches, with the east-central part of the State receiving the greatest rainfall. This extremely heavy rainfall resulted in widespread flooding, land subsidence, and other damages throughout the State.

Following Agnes, several agencies undertook numerous stream channel modification projects which were intended to protect the adjacent land area by increasing the rate of flow through the channel, thereby decreasing bank overflow and reducing flood damages. Many argue, however, that stream channelization is a destructive process, destroying the biological productivity of the natural stream course, and in fact aggravating flooding problems downstream.

The present investigation was undertaken to examine the environmental effects of channel modifications on a selected cross-section of Pennsylvania streams. The primary focus of the study is on the ecological changes brought about by stream alterations implemented both before and after the Agnes flooding.

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METHODS

Six coldwater trout streams, geographically distributed throughout the State of Pennsylvania, were selected for study (figure 1): Mill Creek (Westmoreland County), Beaver Creek (Schuylkill County), Muncy Creek (Sullivan County), Freeman Run (Potter County), Clover Creek (Blair County), and Fishing Creek (Clinton County). Both natural and channelized reaches of each stream were investigated. Geologic, engineering, and biological studies were performed on a total of nine channelized reaches and thirteen natural sections of the subject streams.

A geologic investigation was undertaken to determine the hydrology and morphology of the subject streams and their drainage basins. An engineering investigation was carried out to locate all reaches of channel alteration on the six subject streams. Where records were available, the date and cost of channelization were determined. Flooding conditions during Hurricane Agnes were determined by observing high water marks and by questioning local residents. Field surveyed cross-sections were taken at selected stations.

The surveyed cross-sections and high water elevations were used to compute the cross-sectional area of the flowing water mass during Hurricane Agnes. Maximum streamflows during the flood were computed using Manning's equation as given in Chow (1964). Calculated streamflows were plotted on frequency-discharge, drainage area curves to determine the year frequency of the Agnes event.

Each stream was visited three times during 1974, and physical, chemical, and biological sampling performed. Methods of measurement of chemical parameters were those found in *Standard Methods*, 13th edition. *In situ* measurement of pH, temperature, and specific conductance was made at each study site at the time of sampling. In addition, to illustrate maximum temperature differences, water temperatures were recorded approximately simultaneously at each site on a given stream during the mid-afternoon hours.

Dissolved oxygen was measured using the azide modification of the Winkler method. Samples were fixed at the time of sampling and titrated later the same day. Acidity and alkalinity titrations were performed on the same day the samples were taken.

Samples for analysis of all other chemical parameters (hardness, total phosphate, nitrate, total iron, sulfate, turbidity, suspended solids, and total solids) were taken only during the first (May-June) and final (September-October) sampling trips, and only at the study site furthest downstream on each stream. All samples were preserved following the recommendations of Golterman (1969) and returned to the laboratory for analysis.

Benthic macroinvertebrate populations were sampled using a one square foot Surber sampler. Bottom fauna samples were taken during the initial (May-June) and final (September-October) visits to each stream. Three samples were taken at each site during the initial visit and five during the final visit.

Benthic fauna were identified using taxonomic keys found in Edmondson (1959), Pennak (1953), and Usinger (1971). The total number of individuals of each taxon was tallied. Dry weight was determined by drying each sample in an oven at 60°C for a minimum of four hours, and then weighing on an analytical balance. After examination, the individual numbers and weights obtained from each site were summed and converted to population density (organisms per square meter) and standing crop (grams dry weight per square meter).

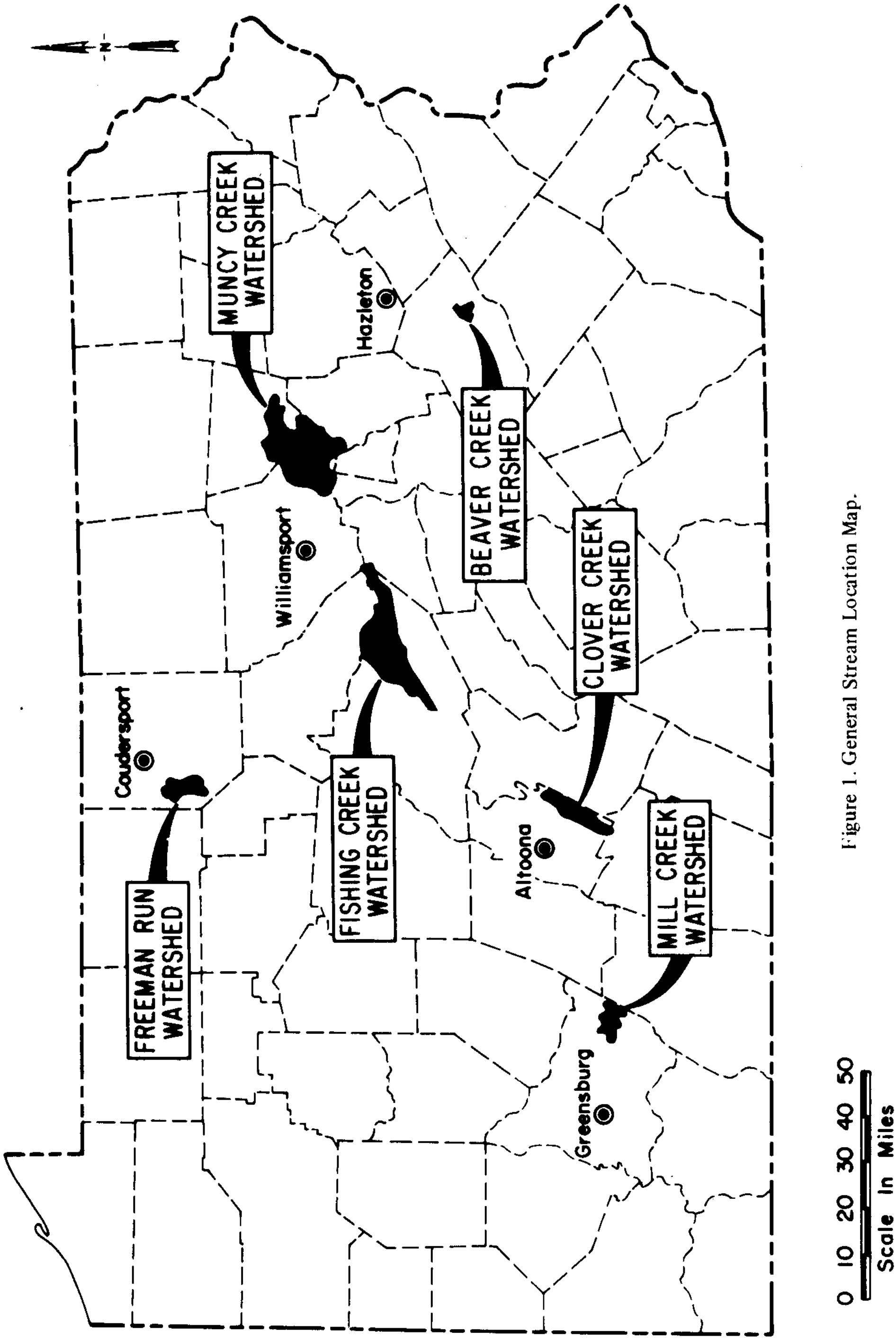

Figure 1. General Stream Location Map.

The Shannon-Weaver index of diversity ($\bar{d}$) was computed for each sample taken, using the computations found in Weber (1973). A composite diversity index was obtained for each study site by taking the mean of the indices computed for the individual samples.

Fish populations were sampled during the July-August and September-October sampling periods using electroshocking techniques. Each stream section was contained with blocking seines and electrofished in an upstream direction. Three electrofishing passes were made through each stream reach using 230 volt AC current (1150 watts). In areas where the conductivity was low (<100 micromhos/cm), blocks of cattle salt were placed upstream of the study site to improve electroshocking conditions. After each pass, all fish collected were sorted by taxon and counted. Each captured trout was individually measured and weighed, while other species were weighed in bulk. All live fish were returned to the stream below the study area before the next pass was made. Where sufficient fish were collected, population estimates and confidence intervals were computed for each species following the multi-nomial procedure of Zippin (1958). Estimates of total non-game species were derived by summing the population estimates obtained for each non-game fish species.

Because the numbers of individuals captured were insufficient for computing population estimates for each species or size class of trout, a single value was calculated for total trout only. Combining size groups in this manner introduces a slight error into standing crop estimates, but this is offset by the added accuracy that is obtained from a larger sample (Sullivan, 1956).

The surface area of each study site was computed as the product of 300 feet multiplied by the mean of five width measurements. Based upon the surface area, fish population estimates were then converted to fish per hectare. Standing crop estimates were obtained by taking the product of the population size and mean weight per fish, and applying the appropriate conversion factors to give kilograms per hectare (kg/ha). The total standing crop of non-game fish was obtained by summing the standing crop estimates for each species.

RESULTS AND DISCUSSION

Watershed Characteristics

The six watersheds are comprised predominantly of agricultural and forested land with a minimum of residential and commercial development. Farms are situated in the stream valleys, while the slopes are generally forested. Residences are located along roads in the stream valleys. Population is sparce with the largest towns having a total population of less than 2,000. Primary activities within the basins are farming and recreation. Mining occurs only to a limited extent in the Clover Creek and the Mill Creek basins.

The differences in geologic characteristics of the watersheds are reflected in the water chemistry of the streams. The watersheds of Clover Creek and Fishing Creek contain considerable limestone deposits. These streams are characterized by high pH, hardness, specific conductance, and alkalinity. The remaining four streams exhibit neutral or slightly acidic pH levels and lower hardness, alkalinity, and specific conductance. These non-limestone streams reflect the predominance of shale and sandstone bedrock in the basins. All streams exhibit good water quality, with the exception of Mill Creek which showed some degradation of water quality in its lower reaches due to the influx of acid mine drainage.

Flood Protection

The streams studied varied in the degree of flooding experienced during Hurricane Agnes. Mill Creek in southwestern Pennsylvania experienced about a 25-year frequency flood, the lowest of the streams studied. The most extensive flooding occurred on Muncy Creek where the Agnes event far exceeded the 100-year flood. The remainder of the streams studied experienced flooding of between 50 and 100 years in frequency.

Channelization was performed on all the streams both before and after the Agnes flooding. Freeman Run, Clover Creek, and Beaver Creek exhibited only a few reaches of channel alteration, but channelization was observed much more frequently on Mill, Muncy, and Fishing Creeks. These were the three largest streams and had the greatest amount of development in their watersheds along the lower reaches.

Channel modifications ranged from general clearing of the channel to extensive dredging of the stream and construction of elevated flood plains and levees. The "typical" channelization project involved clearing and widening of the channel to give uniform flow characteristics and increased channel volume. In addition, bank height was generally increased with spoil materials and the bank stabilized with rip-rap. These activities resulted in a uniform channel clear of obstructions and having a low roughness coefficient. Bank vegetation was usually lacking or sparse. Figure 2 shows a typical natural stream section; figure 3 shows a typical channelized stream section.

Reaches of channel modification observed were generally short, covering stream distances of 0.25 miles or less. For this reason, bank overflow is controlled only on a localized basis, along the channelized reach, and for a short distance upstream.

In evaluating the protection afforded by the channel modifications investigated, it is evident that the channelization performed prior to Hurricane Agnes did little to ameliorate the flooding. The majority of the channelized sites studied provided sufficient channel volume to contain the 10- to 20-year flood, but provided virtually no protection against the Agnes flood. Furthermore, stream flow calculations indicated that flood elevations in stream reaches channelized after Agnes would be only 0.5 feet lower than those actually experienced, should a storm of similar magnitude occur. It must be recognized, however, that the Agnes event was an unusual and large flood, and no stream channelization, save rather impractical and cost prohibitive alterations, would be effective under these conditions.

Aufwuchs

Visual observation at the various study sites indicated an abundance of attached algae at all locations. Except in deep pools, streambed materials were encrusted with diatom frustules. Dense mats of filamentous green algae were occasionally observed in shallow backwater areas.

The algal flora encountered consisted predominantly of diatoms with some green algae and an occasional blue-green. The pennate diatom *Navicula* was the genus most often observed to be dominant. *Cymbella, Fragilaria,* and *Synedra* also occurred as dominants, either individually with *Navicula* or with one of the green algae, *Microspora* or *Ulothrix.*

Figure 2. Typical Natural Stream Reach.
Good Fish Habitat is Illustrated by Current Diversity
Created by Boulders, Variable Water Depth, and Overhanging Vegetation.

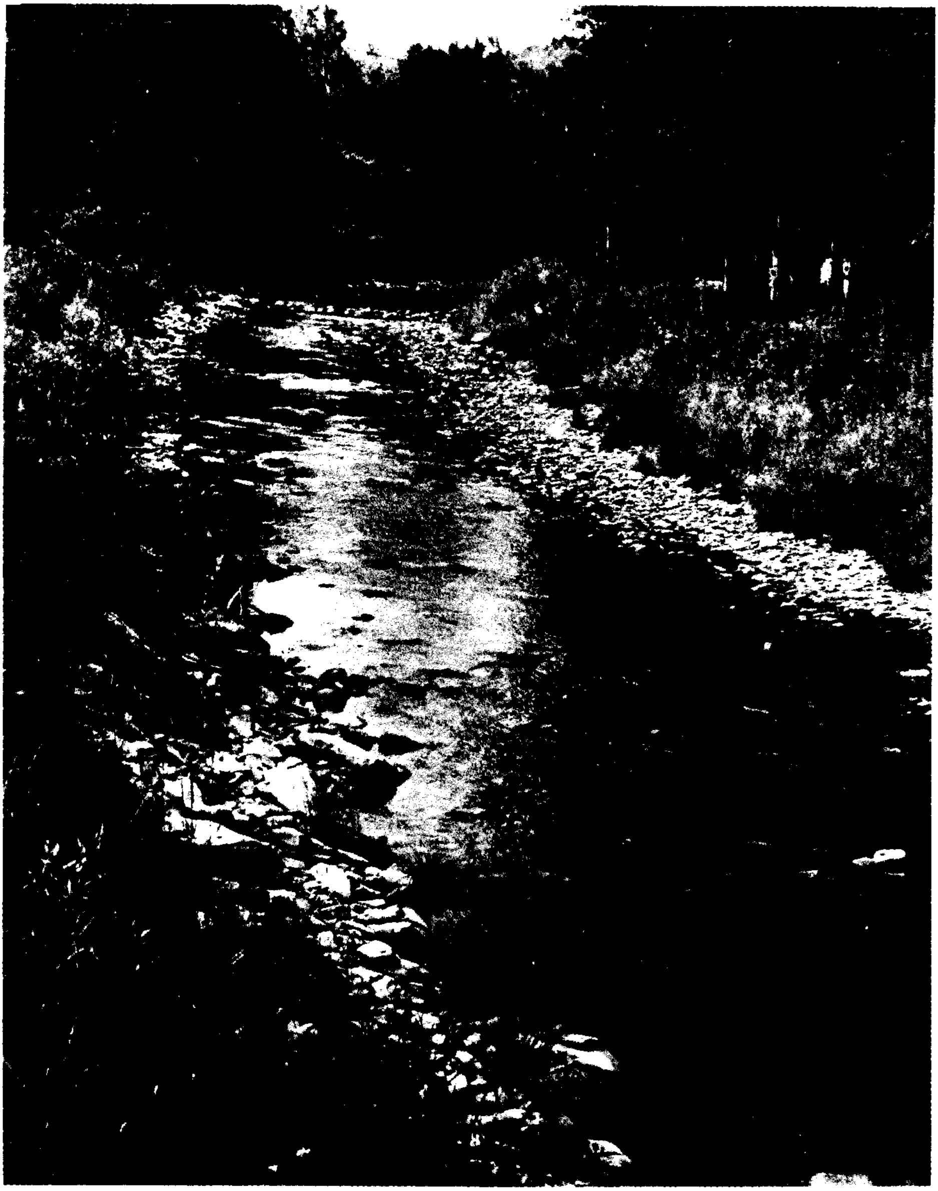

Figure 3. Typical Channelized Stream Reach Approximately Three Years Following Channelization. Poor Fish Habitat is Illustrated by Uniform Cross-Section, Very Shallow Water, Absence of Overhanging Vegetation, and Absence of Channel Obstructions.

The relative frequency distribution of aufwuch genera was one in which a large percentage of the genera were common, a lesser percentage were rare, and only one or two genera were present in truly high numbers. This type of frequency distribution is typical of unpolluted streams (Patrick, 1971).

Within a given stream the aufwuch communities at channelized sites were similar in composition and relative abundance to those at the natural sites. These results suggest that stream channelization has no long term effects on aufwuch communities and there were no disruptions of algal populations which could affect other elements of the aquatic food chain.

Benthic Macroinvertebrates

As expected, all the streams included in the study showed some degree of variation in the composition and abundance of benthic fauna in natural and channelized stream reaches. Despite these differences, within each stream the benthic communities showed a marked similarity in their generic composition at natural and channelized stream reaches. The dominant macroinvertebrate taxa identified are listed in table 1. Within a given stream, the same taxa dominated the benthos at all study sites. In general, the midge larvae (Chironomidae) and mayfly nymphs were the dominant forms encountered on all streams.

In examing the benthic data collectively (table 2), it was found that natural and channelized sites differed little with respect to the number of taxa, number of organisms,

TABLE 1. Dominant Benthic Fauna in the Six Subject Streams.

	Natural Site 1	Natural Site 2	Natural Site 3	Channelized Site 1	Channelized Site 2
Mill Creek	Chironomidae	Chironomidae	Chironomidae	Chironomidae	Chironomidae
Beaver Creek	*Ephemerella* *Stenonema* Enchytraeidae	Chironomidae *Ephemerella* *Stenonema*		Chironomidae *Ephemerella* *Stenonema*	*Ameletus* *Ephemerella* *Stenonema*
Muncy Creek	*Cheumatopsyche* *Ephemerella* *Stenonema*	*Cheumatopsyche* *Ephemerella* *Stenonema*		*Cheumatopsyche* *Stenonema*	
Freeman Run	Chironomidae *Ephemerella* *Stenonema*	Chironomidae *Ephemerella* *Stenonema*		Chironomidae *Ephemerella* *Stenonema*	
Clover Creek	Chironomidae *Baetis* *Hydropsyche* *Stenonema*	Chironomidae *Hydropsyche* *Stenonema*		Chironomidae *Baetis* *Stenonema*	
Fishing Creek	*Brachycentrus* *Cheumatopsyche* *Stenonema*	Chironomidae *Brachycentrus* *Cheumatopsyche* *Stenonema*		Chironomidae *Ephemerella*	Chironomidae *Brachycentrus*

density, standing crop and diversity of their benthic communities. The lack of difference between natural and channelized sites is probably explained by the availability of suitable substratum and habitat for benthic fauna in both natural and channelized stream reaches. The substratum of the channelized sections of the streams included in the study was composed primarily of cobble. The substratum of almost all the natural sections was predominantly cobble with varying amounts of gravel, silt, bedrock, and/or boulders. Thus, while the benthic habitat varied from channelized to natural sites, there was sufficient diversity of habitat in both instances to provide abundant living space for benthic populations to proliferate.

In summary, the benthic data indicate that channelization did not alter the overall composition or size of the benthic community to any substantial degree in the streams which were studied.

TABLE 2. Summary Benthic Macroinvertebrate Data.

Parameter	Month	Natural Sites	Channelized Sites
Mean Number of Taxa	June	9.07	9.44
	September	8.97	8.95
Mean Number of Organisms	June	41.39	48.59
	September	53.31	40.08
Mean Diversity	June	2.27	2.31
	September	2.18	2.31
Mean Dry Weight (mg)	June	68.10	102.80
	September	96.38	80.45
Mean Density (organisms/m^2)	June	386	520
	September	566	431
Mean Standing Crop (gm/m^2)	June	0.769	1.107
	September	1.041	0.866

Fisheries

Figure 4 shows average population densities and standing crops for channelized and natural sites during July and September for both game and non-game species. The overall results indicate the populations of non-game species (excluding suckers) in channelized stream sections were generally equal to or greater than those in natural sections. Standing crop on the other hand was approximately equal at channelized and natural sites in July and slightly greater in channelized stream reaches in September. Thus, while there are a greater number of non-game fish in the channelized areas, the mean weight per fish is less than in natural reaches. The lack of predatory pressure at the channelized stations and the presence of a suitable stream bottom consisting of rocks of relatively uniform size (2.5 to 10 inches in diameter) probably account for the larger populations of non-game species in the channelized reaches.

Trout populations showed considerable differences between channelized and natural stream reaches (figure 4). The mean trout population density in natural stream reaches was 1.5 times greater than in channelized sections in July and 3 times greater in September. Trout standing crop (kilograms/hectare) was also higher in the natural stream sections, being approximately 2.7 and 2.8 times that of the channelized study sites in July and September, respectively. The disparity between the numbers of trout in natural and channelized stream reaches was due mainly to the lack of legal size fish (fish greater than 6 inches in length in Pennsylvania) in the channelized sections. While all size classes of trout were captured at the natural sites, the fish captured at channelized sites were predominantly those of the smallest or sublegal class.

The data in figure 4 indicate that the population estimates and standing crops at both natural and channelized sites were much lower in September than those computed during July. The decrease in the latter part of the year may be due in part to natural mortality. However, it is more likely the result of a reduced capture efficiency in the electroshocking procedure due to unusually high water and reduced specific conductance observed during the September sampling period.

The findings of this study are in basic agreement with those of earlier works; that is, depressed trout populations (and standing crops) occur in channelized stream reaches. Several authors have reported the effects of stream alterations on game fish population and excellent reviews of the subject have been written by Blair (1973) and White (1973).

While it has been established that channelization is detrimental to game fish populations, the mechanisms by which this occurs vary. Stream channelization can affect temperature, sedimentation, nutrition, and physical habitat elements.

The investigation of attached algae, benthic macroinvertebrates, and forage fish indicated that channel alterations have no long term deleterious effects at these trophic levels. Thus, the reduced trout populations in channelized stream reaches are probably not brought about by nutritional factors or disruption of a lower trophic level.

Increased sediment load and high turbidity associated with channelization activity, as well as increased erosion from unstable banks created by channelization projects are other factors which can account for the absence of legal size trout in channelized areas. These factors, however, are not felt to be important in the streams studied. Field observations disclosed very few areas of accelerated bank erosion on the six subject streams.

It has been well documented that water temperature plays a significant role in the occurrence and distribution of fish species. This is particularly so with coldwater fishes such as trout. Temperature variations were found to be significant on several of the streams studied. The most striking temperature variations were found on Freeman Run and Fishing Creek during July of 1975. At a well shaded natural site on Fishing Creek, a temperature of 18.9°C was recorded. One mile downstream the water had a temperature of 20.6°C, an increase of 1.7°C (3°F). Practically the entire length of the stream between these two points has been channelized. A similar situation occurred on Freeman Run between Stations 2 and 1 where a temperature difference of 1.1°C (2°F) was observed. All of the 0.4 miles of stream between the two points of measurement were channelized.

Although these data are limited, they do indicate that where substantial lengths of modified stream channel do exist, a rise in water temperature may occur. Such a temperature increase is most likely to occur on clear sunny days during mid-summer when the absence of natural shade is most significant. It should also be noted that these

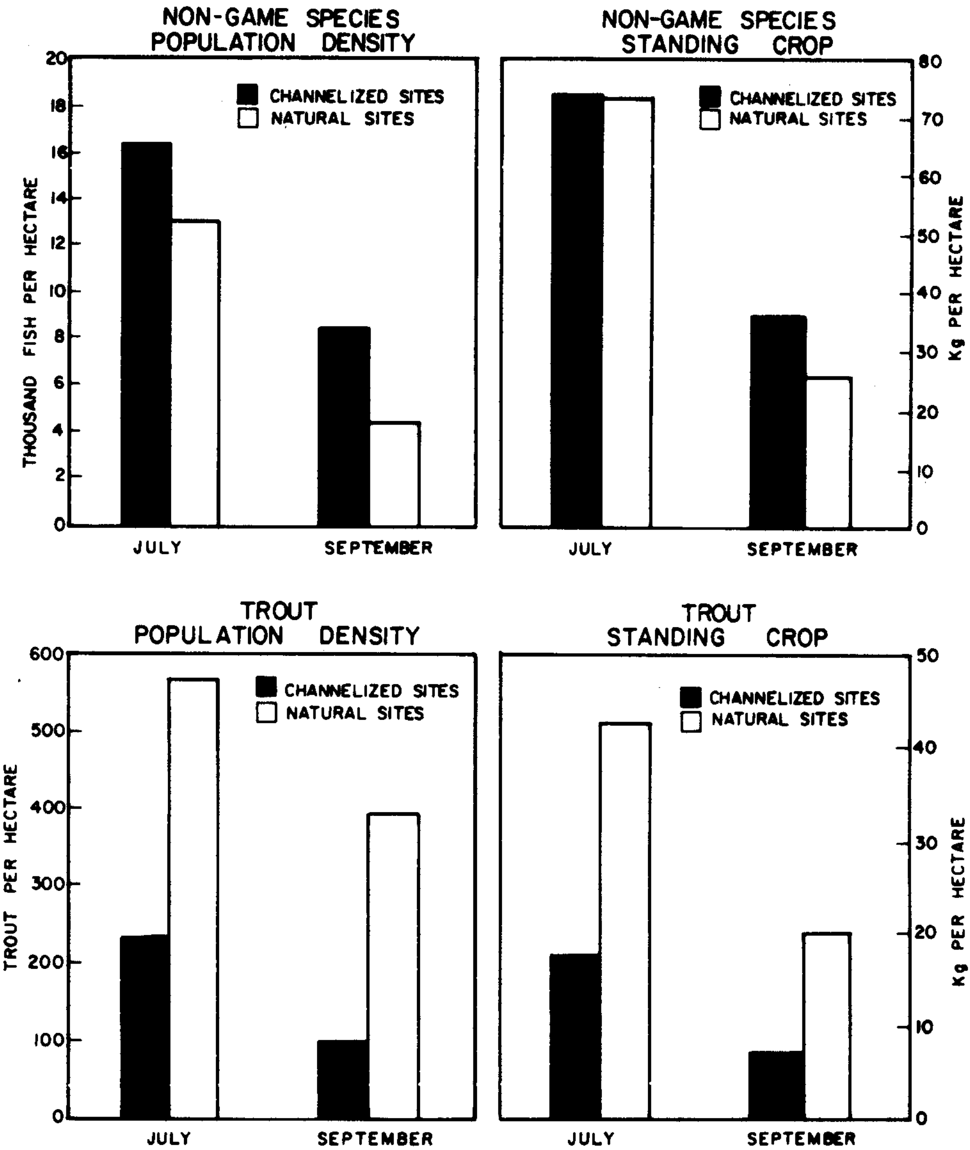

Figure 4. Average Population Density and Standing Crop for Non-Game Fish and Trout in Channelized and Natural Stream Reaches During July and September, 1974.

temperature increases can be cumulative as the water progresses downstream. Water flowing through a number of channelized areas can become progressively warmer as it approaches the mouth of the stream; and temperatures in the lower reaches of the stream may then exceed the tolerable maximum for trout, resulting in the loss of productive sport fishing waters. Such a situation may account for the loss of legal size trout observed on some of the six streams studied.

The results of this study indicate that the major reason for the sparce adult trout populations in channelized stream reaches is the lack of physical habitat, particularly cover. Physical elements such as current velocity, undercut banks, overhanging shoreline vegetation, deep pools, and channel obstructions (i.e., logs and boulders) are extremely important in determining the occurrence and distribution of trout. The study shows that channelized sites were generally lacking in those physical elements which provide good trout habitat. The difference in habitat between natural and channelized reaches is illustrated by comparing figure 2 with figure 3.

Logs, boulders, and other channel obstructions which create a diversity in the current pattern and offer protection to adult trout, are normally removed during channelization. These items, along with undercut banks and overhanging shoreline vegetation provide cover and a place of concealment for trout. All trout, particularly brown trout, exhibit some degree of negative phototropism. For this reason, they are most often found under logs, undercut banks, overhanging vegetation or any other object which provides overhead cover.

Again, the process of stream channelization normally destroys the entities providing cover for trout. Submerged logs are removed; stream banks are defoliated and graded; and the stream is straightened, thereby removing the bends and meanders where undercut banks usually occur. In addition, channelization often results in the loss of areas of deep water, a form of protective cover in itself and a critical survival item during periods of drought.

Sport Fishing Losses

An effort has been made to evaluate the recreational impact resulting from reduced fishing activity as a result of stream channelization after Agnes. If it is assumed that a stream reach which is channelized no longer supports legal size trout, (and the data gathered in this study indicated that this is the case), then it follows that the stream reach is lost as a sport fishery. Surveys performed by the Pennsylvania Fish Commission indicate that an annual average of 500 fisherman days per mile of stream is a realistic statewide average of fishing pressure in the state.

The *1972 Flood Damage Assessment Report* (1974) indicated that approximately 300 stream miles were channelized in the State of Pennsylvania following the Agnes flood. The Pennsylvania Fish Commission estimates a monetary value of approximately $35 per day of fishing. Using an average of 500 fisherman days per mile at a cost of $35 per day and 300 miles of channelized stream, it is calculated that a potential loss of $5.2 million dollars will occur annually to the economy of the state. This loss is added to when one considers the trout habitat lost due to unsuitably high water temperatures brought about by channelization upstream.

Of course it cannot be assumed that for every mile of stream channelized 500 fisherman days of angling activity are lost, since some of the activity would be shifted to the remaining natural reaches of a given stream. However, as more stream mileage is channelized, reducing overall stream aesthetics, and forcing more fishing activity onto shorter stream distances, the angler would be less included to frequent Pennsylvania's waterways.

CONCLUSIONS

Based upon the data gathered during this investigation the following conclusions can be drawn.

1. Stream channelization, as observed on the six streams investigated, is ineffective in providing protection from flooding of the magnitude occurring during Hurricane Agnes. In general, the observed channel modifications provide protection from floods having up to a 10- to 20-year frequency.
2. There appear to be no residual effects of stream channelization on water quality of the six streams investigated.
3. Channel modification appears to have no long-term deleterious effects on forage fish species, attached alge, or benthic macroinvertebrates. Thus, it can be concluded that reduced trout populations in channelized stream reaches are not the result of disruption of a lower trophic level.
4. Stream channelization has a direct, deleterious impact on trout populations. Modification of stream channels removes the physical elements comprising good habitat for trout, particularly larger trout. Most serious are the removal of overhead cover and the elimination of deeper water pockets and pools.
5. The reduced fishing activity brought about by sport fishery losses resulting from post-Agnes stream channelization represents a potential yearly loss of over $5 million to the Pennsylvania economy. The absolute loss is difficult to compute, since it is not known what percentage of the fishing activity is transferred to the remaining natural stream reaches.

ACKNOWLEDGMENT

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