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16. Abstract:

This report contains a literature review of articles and books pertaining to the design and impact of channel modifications on the riverine system. Principal components in understanding such impacts are the geomorphology of the stream system, the impact of bridge and culvert structures on streamflow characteristics, and the relation of the stream system and changes in it on riparian ecology.

Any change in a stream impacts the equilibrium of the stream. These impacts can result in a decrease or increase in base level which can be propagated in both the upstream and downstream directions with serious impacts on the stream and other structures crossing the stream. A design method which considers this possibility was developed by the Ontario Ministry of Natural Resources, based on research by David Rosgen and others. The approach is based on understanding which components of stream dynamics are in equilibrium and constructing designs that maintain stream equilibrium.

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CHANNEL MODIFICATION
Literature Review

by

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DEPARTMENT OF CIVIL ENGINEERING

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Not intended for construction, bidding, or permit purposes. The engineer in charge of the research study was David Thompson.

CHAPTER I

CHANNEL MODIFICATION MITIGATIN BIBLIOGRAPHY

REVIEW OF FLUVAL GEOMORPHOLOGY

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REVIEW OF FLUVIAL GEOMORPHOLOGY

Stream channels do not remain fixed in shape or position over time, but change naturally in response to a variety of interrelated variables. Predicting how, and how rapidly, stream channels change has proven to be a difficult task because many of the parameters that influence channel shape and position are interrelated and difficult to model. Change in channel morphology also occurs over a varied time scale from hours to days, years, decades, centuries, or millenia.

The study of how natural stream channels change, and in so doing shape the surrounding landscape, is a discipline of geology and geography known as *fluvial geomorphology*. Aspects of fluvial geomorphology have been studied for more than a century, resulting in an extensive published literature of many thousands of papers scattered over many disciplines. The literature of geology and geography has been concerned primarily with the long-term response of streams to natural changes that occur over centuries or millennia. In contrast, the traditional engineering literature has been concerned primarily with the short-term reactions of streams to human modifications such as daming, staightening and deepening of channels, to the emplacement of channel crossings and flow control measures, and changes in land use observed over a span of days, years, or decades. Hence, the time perspectives of the geomorphologist and engineer differ. Changes induced by man often mimic, or are at least comparable to those produced naturally, and so offer accelerated "experiments" for prediction of natural changes that occur on a grander scale and too slowly to observe in a human lifespan. As such, engineering modifications to stream channels offer a "laboratory" for geomorphologists to study the results of varied impacts on stream channels. In recent years, collaboration between geomorphologists and engineers has resulted in an improved general understanding of river behavior, useful at the engineering time-scale, but it remains difficult to accurately forecast the long-term behavior of river systems.

The subject of fluvial geomorphology is relevant to engineering of stream channel modifications, particularly with the growing environmental "awareness" of the public and government, and the requirement that engineers and geomorphologists respond to a broad range of "environmental" questions that are often beyond their traditional areas of expertise. An understanding of how natural stream channel systems behave assists in engineering successful and "environmentally sensitive" channel crossings, erosion control measures, and flow regulating structures; and so a brief summary of this subject is given below. If in new designs of stream channel modifications, an attempt is made to preserve, enhance, or restore the "natural" conditions in a stream channel, it is important to assess those changes that result from the "natural" behavior of a stream versus those that are a result of human activity. Modern case studies, reviews, and engineering manuals indicate that it is possible to accomodate some natural channel change and environmental features in the design of crossings and other channel modifications without sacrificing the integrity or hydraulic efficiency of structures. The qualitative summary given below is based on review of the recent published literature, concentrating on the modes and rates of change in natural stream channels, and the impact of human activities on stream channels. This annotated literature review is organized into the four following sections:

- book-length summarys, textbooks, symposia, and manuals surveying the entire subject
- short, paper-length reviews covering specific topics on channel behavior
- case studies of individual streams, channel reaches, and case histories documenting the effects of human modifications on stream channel behavior
- laboratory studies that simulate natural channel systems or model engineered channel structures, theoretical and mathematical models for stream channel behavior, and empirical field studies that document factors controlling channel behavior

Several, very thorough reviews of this subject have recently been given by Brookes (1988), Chang (1988), Gore (1985), Gregory (1977), Hickin (1983), Park (1981), Rhodes and Williams (1979), and Schumm et al. (1984). The following generalizations are based primarily on these works.

KINDS OF CHANGE

A natural stream channel establishes a relatively stable "equilibrium" morphology that reflects a given discharge of water and sediment. Nevertheless, *even if left undisturbed*, the morphology of a stream channel changes over time, and if the "equilibrium" conditions are disturbed, additional change occurs to establish a new equilibrium channel morphology. A channel may change its *position* (location of the channel axis in map view or planform), *shape* (width and depth), and *bed character* (grainsize and bedform) over time in several ways, and change in channel morphology may occur gradually, episodically, or as a series of "waves" of change transmitted upstream or downstream. Moreover, change may occur over the entire length of a channel system simultaneously, or may be localized at a particular point in the channel at a given time. There is a time-lag between the onset and resulting impacts of morphologic change, and a complex feed-back between processes effecting change, so there is often a long response time required for the full effects to be felt. There are perhaps six major ways in which channel morphology may change.

1) Lateral Migration - The position of a stream channel in map view or "planform" may shift laterally by erosional retreat of one or both banks. The change in position of the channel axis while channel dimensions remain uniform is referred to as *lateral migration*. In contrast, *channel widening* (or narrowing) may occur while the position of the channel axis remains relatively fixed. Highly sinuous or meandering stream channels experience slow but predictable lateral migration of the channel axis in response to secondary helical flow along curved channel reaches. Erosion of the outer banks on meander bends is usually accompanied by sediment aggradation on the adjacent inner bank, so that the channel dimensions remain uniform while the position of the channel migrates. The phenomenon of translation of channel bends has been very well documented in many case histories of natural stream channels, and has been replicated in laboratory flume experiments, as well as modelled theoretically. Braided stream channels also experience channel migration and widening, although this phenomenon is often more rapid, less regular, and less predictable. Channel widening by bank failure, without lateral translation of the channel, is often a secondary response to deepening and incision of the channel. Both lateral translation of the channel, and channel widening, may occur by gradual incremental bank erosion or rapid episodic bank failure. The rates of channel migration and channel widening vary widely with the scale and discharge of the stream, the magnitude of peak discharge events, and the character of the channel bed and bank materials. Although natural channel migration occurs slowly, many case histories demonstrate that this process is important even on the short-term engineering time scale.

2) Downcutting or Incision - Deepening or lowering of the channel by erosional scour of the bed may occur gradually over an extended period of time, or rapidly during individual flood events. Gradual, long-term, downcutting is probably characteristic of most stream channels, particularly in the headwater regions of tributary drainages. The rate of downcutting varies with the stream gradient and the character of the bedrock and alluvial bed and bank materials. Rapid, short-term, downcutting occurs during individual flood events, but is often balanced by later sediment aggradation during the waning stages of floods. Local intensified erosional scour around bridge piers and at culvert outlets has been studied in great detail, and is also often of short duration but high magnitude, resulting in many documented cases of bridge failures. Downcutting may be distributed over the entire length of a channel or localized along the channel at discrete steps or "knickpoints" that typically migrate upstream over time. Relatively rapid historical channel incision by gullying, headward erosion, headcut migration, and knickpoint migration, is important on an engineering time scale, and has been described in many streams, particularly in arid regions where it has been related to change in land-use or climate. Rapid downcutting is also a well-documented upstream response to channel straightening and increase in gradient.

3) Aggradation - The deposition of sediment in the bed of a channel and/or on one or both banks is common to virtually all streams. Stream channels transport sediment continuously and/or episodically depending on discharge, but at any point in time a great deal of sediment is temporarily "in storage" within the channel and along the banks, and the channel geometry reflects a long-term balance between alternate periods of erosion, transport, and deposition. Most modern river valleys exhibit long-term evidence for alternating periods of channel and flood-plain aggradation, and periods of channel incision and flood-plain degradation. The factors that bring about aggradation of sediment within the channel, either on a short-term or long-term, are complex and related primarily to change in stream gradient brought about by baselevel change. Localized channel aggradation associated with natural or man-made channel obstructions, and aggradation in response to reduction in discharge or suppression of peak discharges by flood control measures, is important on an engineering time scale. Aggradation is also a well documented downstream response to natural or artificial channel straightening by meander cut-off.

4) Change in Texture or Form of Bed Material - The grainsize, sorting, and form of the bedload material in a stream channel reflect its gradient, dominant discharge, and sediment transport capacity. The character of the bedload sediment in stream channels may change over time in response to natural change in climate or stream discharge, contribution by tributary drainages, daming, or changes in land use in the drainage basin. The selective removal of fine sediment from the bed load, and lagging of coarse sediment to armor the bed with a pavement of relatively immobile large particles has been commonly observed downstream from dams. Changes in the bedload result in a change in the hydraulic character of a channel, and lead to changes in channel morphology.

5) Growth or Removal of Channel and Bank Vegetation - Vegetation within a stream channel, and along the banks, plays an important role in stabilizing the channel position, and in reducing the rate of bank erosion and inducing sediment aggradation. Natural changes in climate may bring about vegetation changes that have an impact on channel geometry. Introduction of non-native kinds of vegetation by man, and removal of natural channel obstructions by snagging and dredging of fallen logs and other debris jams, may also result in changes in channel geometry.

6) Abandonment or Re-activation of a Channel - A natural stream channel may be partially or completely abandoned and cut off from active flow. The process of *meander cut-off*, has been well documented as a natural consequence of bend migration in meandering streams. Similarly, the process of *chute cut-off* and development of *slough channels* is well documented in braided streams and low-sinuousity meandering streams. The complete abandonment of an entire reach of a stream, by *avulsion*, has been well documented. Once abandoned, a stream channel may be later re-activated by natural flow diversion. These are all natural processes by which a river system alters or improves its gradient over time. Of course, many engineering efforts are aimed at preventing this natural process from occuring. In contrast, engineered artificial meander cut-offs and other forms of *channel straightening* have been undertaken to improve channels for navigation and reduce flood stages. Apart from the obvious change in channel morphology brought about by channel abandonment, the associated decrease in stream length and increase in stream gradient , results in change in channel morphology both upstream and downstream from the cut-off.

FACTORS THAT INFLUENCE CHANGE

The literature of both geomorphology and engineering contain many case studies of stream channel change as a consequence of natural processes and engineering modifications. Theoretical and empirical relationships based on observations of natural streams, and on laboratory flume experiments, have been developed to relate the host of variables to resulting changes in channel geometry. Many qualitative and quantitative relationships have been developed for specific streams or stream types, or based on limited data sets for a number of streams, and so the more general applicability of these relationships has been questioned. The response of river systems to change is complex because of these interrelationships and the feed-back among processes. Nevertheless, a few qualitative generalizations may be made from these relationships, and these seem to be applicable to most stream channels. The typical consequences of change may be discerned from this literature.

There are perhaps ten major factors that are important in controlling the rate and magnitude of change in channel morphology. It is variations (natural or induced by man) in these parameters that drive the kinds of change in stream channels listed above. Change in one parameter seldom occurs alone, but in concert with changes in other parameters. Hence, because of this interrelationship, it is often difficult to separate "cause" and "effect." A change in one parameter at one point along a stream channel sets in motion a series of processes that induce changes in other parameters both upstream and downstream. Hence, a natural or artificial change at one point along a channel cannot be viewed in isolation without considering or anticipating change that is occurring, or will occur, both upstream and downstream.

1) Scale of Channel - Stream channels vary from small rills, gullies, and arroyos with drainage basins on the order of a few square kilometers, to large rivers that drain a major part of a continent, with drainage basins in thousands or millions of square kilometers. The magnitude and rate of change in channel morphology obviously varies with the scale of the stream and its drainage basin. Natural change in scale may be brought about by change in climate, tectonic activity, or change in the size of the drainage basin by stream capture. Human activity may also result in change of scale by interbasin water diversion, damming, abstraction of water for irrigation, or other activities that result in a change in discharge. Large rivers exhibit a potential for a greater magnitude and rate of change than smaller rivers. Of course, their tributary streams are still smaller in scale and so the potential magnitude and rate of change is proportionally less. Most modern rivers exhibit channel morphologies (width, depth, meander wavelength, and sinuosity) that are smaller in scale compared to the morphologies of the valleys in which they reside, and so are said to be *underfit* by geomorphologists. This is a result of recent change in climate and reduction in discharge that has occurred over the past several hundred thousand years. Continued and on-going reduction in the scale of channel morphology has been documented on many modern rivers that have been dammed along their length.

2) Hydrology - The discharge characteristics of a stream channel, the frequency and magnitude of discharge events, and hydraulics of flow (depth and velocity), vary with climate and the scale and slope of the channel and the bed characteristics. All streams experience natural short-term variations in hydrology in response to daily, seasonal, or long term variability in precipitation, and also in response to longer term climate cycles. Human activity may also result in change in hydrology by withdrawal of water, urbanization or other change in land use within the drainage basin, and flood control measures that suppress peak discharge. Channel morphology reflects in part the dominant discharge experienced by a stream, for example the "bankfull" discharge or typical mean annual flood discharge, and also the effects of extreme discharge events. Hence, changes in discharge result in changes in channel morphology.

Many stream channels in arid and semi-arid regions are ephemeral, and rarely contain flowing water except during the rainy season. In humid regions, streams are typically perennial and flow all the time. Many streams have both perennial and ephemeral segments or "reaches." This is often due to gain or loss of water to the ground water system (gaining or effleunt streams versus losing or influent streams). Tributary streams are often ephemeral in their upper reaches, but sustain perennial flow downstream where they recieve water from contributing tributaries and ground water discharge. Hence, channel morphology typically changes along the length of a given stream. Most large rivers have experienced dramatic changes in hydrology over the past several decades in response to reduction in spring flow as a result of ground water withdrawal, and construction of dams, which typically increase base flow but suppress peak discharges. As a result, the channel morphology in virtually all rivers is undergoing long-term change to reflect the new discharge conditions.

A decrease in stream discharge, or suppression of peak discharges, typically results in aggradation of sediment within the channel and steepening of the channel gradient. This is accompanied by a decrease in width and depth of the channel, as well as braiding and often increased channel vegetation. A decrease in discharge may occur naturally in response to climate change, or stream capture. Such a change may also occur in response to human activities such as daming, removal of water for irrigation or diversion of water from a channel.

An increase in stream discharge typically results in downcutting (deepening) of the channel, an increase in width of the channel, reduction in channel vegetation, and lessening of the slope. Natural climate change, or stream capture may result in an increased discharge. Human activities such as input of wastewater or water from other sources, urbanization and increase in surface runoff may also result in increased discharge.

3) Shape of Channel - There is a great deal of variation in the shape of natural stream channels, and this has been the subject of much published literature in geomorphology. Broadly speaking, however, variation in channel shape spans a spectrum from braided to meandering patterns. Braided streams typically have multiple active and inactive channels, that exhibit a rapid rate of lateral shifting. Such channels usually have a wide symmetrical cross-section with high width/depth ratio. Braided streams are often characterized by a relatively high gradient and ephemeral or flashy discharge, and carry a high bedload and/or coarse bedload sediment. The channel banks are usually composed of weak bank materials (older alluvium of the stream, which consist of unconsolidated sand and gravel). Meandering streams have variable channel sinuousity and typically only a single active channel that exhibits a relatively low rate of lateral shifting. These usually have a narrow asymmetrical channel cross-section with low width/depth ratio. Meandering streams typically have a low gradient with perennial discharge, and carry a high suspended sediment load and/or fine bedload sediment. The channel is typically incised within cohesive bank materials (older floodplain deposits of consolidated silt and clay). Braided channel patterns are typically present in arid and semi-arid mountainous and plains regions, while meandering channel patterns are typical of coastal plain regions.

Changes in channel pattern may be brought about by natural long-term change in climate, resulting in a change in vegetation and sediment load. A change in channel pattern also may be induced by man in response to daming or change in land use that results in change in stream gradient, sediment load or channel vegetation.

4) Slope of Channel - The longitudinal profile or gradient of a stream channel varies along its length and over time. Channel gradient may change over time by gradual downcutting or aggradation, and in response to change in the baselevel to which a stream is graded. Stream gradient effects the hydrologic conditions and the capacity of a stream to transport sediment. Hence, a change in gradient will induce change in flow conditions that result in either deposition or erosion of sediment, and in turn changes in channel geometry (width, depth, and pattern). An increase in stream gradient brought about by channel straightening, for example by meander cut-off, typically results in aggradation of sediment downstream, and widening, shallowing, and braiding of the channel.

A rise in baselevel results in lowering of the channel gradient and propagating upstream aggradation. Natural rise in baselevel may occur in response to landslides or otherwise impounding a stream's drainage resulting in lake formation, a rise in sea level, or the migration of trunk stream away from the mouth of its' tributary. Dam construction and impoundment of a reservoir will also result in a relative rise in baselevel for streams draining into the reservoir.

A drop in baselevel results in steepening of channel slope and propagating upstream downcutting. A natural fall in baselevel of erosion can result from evaporation of a lake, lowering of sea level, or migration of a trunk stream toward the mouth of a tributary. Human activities such as draining of a lake, shortening of stream length by channel straightening or elimination of a meander loop can also produce a relative fall in local baselevel of erosion, resulting in local steepening of channel gradient (a "knickpoint") that propagates upstream over time.

5) Nature of Bed and Bank Materials - The character of the bed and bank materials in a stream channel are collectively dictated by "geologic factors" such as the relief of the drainage basin, the rock types and structure present in the drainage basin, the valley dimensions, and the previous climate and hydrology (paleoclimate and paleohydrology) of the stream, which influence the character of the older alluvium in the stream valley. Some streams exhibit a bedrock-confined channel, where the stream channel is incised into relatively resistant rock. Many tributary streams of larger rivers in the headwaters of their drainage basins are incised into relatively resistant bedrock. More typically, stream channels in their lower reaches are incised within less resistant older alluvium that partly fills the stream valley. Alternatively, the bed of the channel may be in bedrock, while the banks are in older alluvium or soil. The character of the bed and bank materials influences the magnitude and rate of change that a stream channel may experience. Bedrock-incised channels typically will not experience the potential for rapid short-term lateral migration or downcutting shown by alluvial channels.

6) Nature of Sediment Load - Streams carry coarse sediment such as gravel and sand in traction or creep along the floor of the channel (*bedload*), and fine sediment such as silt and clay suspended in the water (*suspended load*), or a varied proportion of both (*mixed load*). The grainsize and sorting of bedload sediment, and the presence and scale of bedwaves (ripples, dunes, bars) on the channel floor influence the hydraulic geometry of the stream, and in turn the channel morphology. Changes in the sediment load will bring about changes in channel morphology.

An increase in bedload transport, or coarsening of the bedload sediment, typically results in aggradation of sediment in the channel, shallowing (decrease in depth) of the channel, an increase in width, braiding, and steepening of the channel gradient. In sinuous channels, this also results in an increase in meander wavelength and decrease in sinousity. An increase in bedload sediment may be brought about naturally, for example by introduction of landslide or other mass-wasting debris, contribution from tributary drainages, or climate change. A similar change in stream sediment load may also be induced by man, for example by contributing waste from mining operations, desilting of irrigation water and return of silt to the channel, or increased erosion in the catchment area (by forest clearing, overgrazing, increase in area under cultivation, or construction activities in an urbanized watershed). Channel straightening, for example by natural or artificial meander cut-off, commonly results in an increased downstream sediment load and aggradation of sediment within the channel. An increase in sediment load is a common problem encountered in the early construction phases during urbanization of a drainage basin.

A decrease in bedload sediment available for transport typically results in downcutting (deepening) of the channel, a reduction in channel width, and a lessening of channel gradient. In sinuous channels, this also results in a decrease in meander wavelength and increase in sinuousity. A decrease in sediment load may occur naturally by climate change that leads to increased vegetation in the watershed. Simlar change may be induced by man, for example by damming, resulting in sediment retention in a reservoir, removal of alluvium for construction aggregate, improved land use practices (soil conservation), or urbanization of a drainage basin. This is a well known problem associated with stream channels downstream from reservoirs, particularly large reservoirs that abstract virtually all the streams' sediment. This is also a common problem found in the later phases of urbanization of a watershed.

7) Vegetation of Bed and Banks - The type and density of vegetation in the channel and banks, and the presence of channel obstructions such as fallen logs and flood debris accumulations influences channel geometry. Vegetation may change in response to natural climate variation, introduction (purposefully or accidental) of new riparian vegetation species, overgrazing, forest cutting or change in land use within a drainage basin (for example an increase in area cultivated, or urbanization).
An increase in channel vegetation typically results in sediment aggradation within the channel, narrowing of the channel, and an increase in channel roughness. Natural climate change may result in an increase in vegetation. The introduction of new riparian vegetation species by man often has a dramatic effect on channel geometry. A decrease in channel vegetation often results in downcutting, channel widening, reduction in bed roughness, increase in sediment yield, and an increase in the rate of lateral channel migration. Natural climate change may result in a decrease in vegetation. Human activities such as overgrazing of livestock, forest clearing, or urbanization may result in removal of channel bank vegetation.

8) Position in Meander Train or Riffle/Pool Sequence - Most natural streams show a regular or periodic downstream alternation between relatively shallow channel intervals with fast-flowing water and a steeper water-surface gradient ("riffles"), and relatively deep channel intervals with slow-flowing water and with a low water-surface gradient ("pools"). Riffles are generally associated with accumulation of coarse bed material and are usually located at inflection points in the channel axis. Pools are usually located along curves in the channel axis and have finer bed material with flanking sand bars. Disruption of the natural riffle/pool sequence during severe flood events, or by channel dredging and snagging, typically results in propagation of channel morphology changes both upstream and downstream.

9) Climate - The amount of annual precipitation, temperature, and seasonality in a river drainage basin influence the discharge, nature of vegetation, and sediment character in a stream channel. Arid climates tend to result in a high bedload sediment, flashy or ephemeral discharge, sparse vegetation, and braided channel patterns. Humid climates tend to favor high suspended sediment loads, perennial discharge, more vegetation, and meandering channel patterns. A long-term change in climate will set in motion a series of processes that result in a new equilibrium channel morphology.

10) Time Scale of Observation - Apart from the influence of man, most natural stream channels attain a state of equilibrium reflecting a balance between the parameters that govern channel morphology. Even under equilibrium conditions, change in channel morphology is still taking place, and so this is often referred to as a "dynamic" equilibrium by geomorphologists. High magnitude short-term events (major floods) produce rapid, obvious, and often dramatic changes in stream channels (deep scour, bank failures, aggradation). However, these changes are often not long-lasting, and their effects are often obliterated during sustained periods of moderate flow or during subsequent flood events. Instead, more frequent events of moderate magnitude account for much of the long-term geomorphic "work" in a river system, and are the dominant agent of slower and less obvious long-term change in channel systems. Natural change often takes place slowly, over a span of decades or centuries, and so may be almost unnoticeable during a human lifespan. However, because very few truly long-term records of channel change exist (for example, over a span of centuries), predictions are based on short-term observations. Hence, the time-scale of observation is important in understanding the direction, magnitude, and rate of change in channel morphology. Long-term changes in channel morphology over "geologic" time may not be important when considering the projected life-span of engineered channel modifications. Conversely, short-term changes in channel morphology, that are very important to consider on an "engineering" time scale, may have little impact on the long-term evolution of a river system. Regardless, it is necessary to specify the time frame when considering the potential impacts of change in channel morphology.

PROSPECT

Most modern rivers and their drainage basins are today so thoroughly modified by human activity that it may no longer be possible to seperate on-going "natural" change from changes induced by man. The long response time required for rivers to adjust to change indicates that most rivers are still responding to change induced by human activities decades ago, as well as those occurring today. It remains difficult or impossible today to accurately forecast the direction, magnitude, and rate of change in stream channel morphology in any quantitative way. In order to fully understand or predict the future *long-term* course of channel change, or the long-term impact of a particular channel modification, a point in a stream channel cannot be viewed in isolation. The *entire drainage basin* must be analyzed, and if a tributary stream is considered, it must be viewed in context of the entire trunk stream drainage basin. The past history of the drainage basin, and the direction and rate of change in the previously undisturbed system, as well as the progress of any upstream-propagating change must be specified. The extent of present modification and land use in the drainage basin must be known, and a forecast for future modification and land use, as well as a prediction of the impacts of these changes must be made. Obviously, the likelihood that it will soon be possible to *quantitatively* predict the course of future channel change seems remote. Nevertheless, it is certainly possible to qualitatively forecast such changes over time. Of course, for "short-term" engineering purposes, it is both necessary and reasonable to assume that an "equilibrium" channel morphology and hydraulic geometry exists, in order to design channel crossings and modifications; because for the most part, channel morphology changes are slow enough not to have an impact during the projected life spans of many structures. Similarly, attempts to enhance or restore the "natural" conditions in stream channels must also be viewed as temporary "short-term" modifications to a system that is unstable in the long-term, and likely responding to various changes, the directions, magnitudes, and rates of which are not well understood.

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CHAPTER II

CHANNEL MODIFICATION MITIGATIN BIBLIOGRAPHY

HYDRAULIC STRUCTURES

CHAPTER II
CHANNEL MODIFICATION MITIGATION BIBLIOGRAPHY
HYDRAULIC STRUCTURES

The engineering of channels has a history dating back to the Roman empire. Since that historical beginning, engineers have designed channels for conveyance of potable water and for drainage of storm runoff. In creating and evaluating their designs, one of the problems engineers face is the propensity for moving water to detach and transport the material which forms the boundary of the channel. The literature presented in the following sections was extracted and compiled from texts and journal articles dealing with the mitigation of the impacts of channel modifications on natural river systems. The citations can be grouped into several classes based on the component or type of treatment discussed.

Hydrology and Bridge Hydraulics

One of the principal factors prior to designing a bridge or culvert section is developing a design flow for the required return interval. Several methods were developed to deal with this problem. The most common approach for small watersheds is the rational method. This procedure and it's parameters are widely documented (for example, Viessman *et al.*, 1989). For larger watersheds, the unit hydrograph method is often applied to develop peak discharges from design rainfall events and rainfall-runoff indices (for example, Viessman *et al.* 1989). In addition, departments of transportation often develop internal procedures for estimation of peak runoff intensities for design flood events (for example, Eash, 1993 and Roth, 1985).

Given a design discharge at the site, the second problem the designer faces is development of the bridge cross section or culvert dimensions. Several procedures are available to attack this problem. Design charts (Harrison *et al.*, 1972) are sometimes used, especially for culvert analyses. For larger structures, the process is often iterative, with use of water surface profile tools (such as WSPRO and HEC-2) for analysis of culvert or bridge hydraulics. In general, development of design discharges and hydraulic analyses are well documented in the literature and these components are widely understood by TxDOT designers.

Bridge Scour

Because of the attention focused by the U.S. Federal Government on bridge scour problems, the literature is rich with regard to analysis and mitigation of bridge scour. (See Brabets, 1994; Fischer, 1995; Hayes, 1993; Holmes and Dunn, 1996; Keefer *et al.*, 1980; Leopold and Maddock, 1953; Smith and Maderak, 1993; Waltemeyer, 1995; and Wilson and Turnipseed, 1994 for examples.) However, because of this same focus, state departments of transportation are generally well aware of these problems and their solutions. Therefore, this part of the literature review was directed toward other parts of the stream and river design problem. A brief summary of some bridge scour articles follows.

Bridge scour can be classified into three primary components: general scour, contraction scour, and local scour (Hayes, 1993). Total scour at a point is the sum of all three components. General scour is the general lowering of the stream channel and can occur whether a bridge is present or not. Contraction scour results from the local increase in velocity as a result of reduced flow area through a bridge opening. Local scour occurs as a result of turbulent eddies which form at changes in the flow field, such as near bridge piers, the end of a dike, and so forth.

Methods for analyzing bridge scour are described by Fischer (1995). The procedure described is an application of the HEC-18 scour equations using a gradually-varied water surface profile model such as WSPRO or HEC-2 (now HEC-RAS). Holmes and Dunn (1996) present a simplified approach based on envelope curves developed for the State of Illinois. The importance of scour estimates and the implications for underestimating scour for design of bridges and other hydraulic structures is discussed by Brabets (1994).

Channel Stabilization

Whenever the shear stress of flowing water exceeds the resistive capability of channel bank material, bank erosion will occur. The balance between channel hydraulics and channel stability is dynamic and not limited in scope to a single point on the river (Turnipseed, 1994). In fact, fixing the location and geometry of a channel at a single point may have disastrous impacts on channel segments located significant distances from the fixed point (Keefer, 1980). Therefore, channel stabilization can be most effective if consideration is given to channel geomorphology and hydraulics (Smith and Maderak, 1993).

In the literature, two broad approaches to channel stabilization are described. The traditional approach has been use of structures such as dikes, revetments, and channel linings. These are placed to mitigate channel erosion and movement (Morris and Wiggart, 1972; Przedwojski *et al.*, 1995; Petersen, 1986; Petts and Calow, 1996). Such structures are commonly applied to large river systems, such as the Mississippi River and Arkansas River. An alternative approach using vegetation and other natural materials was suggested by Gray and Leiser (1977). This approach has been termed *biotechnical* because it implies use of technology in conjunction with biological materials. This particular method has promise for TxDOT use.

Guide banks are a form of dike used to direct flow toward a bridge opening (Neill, 1973). When properly applied, they can be used to confine flow to a single channel, improve the flow distribution across a channel cross section, modify the angle of attack of the flow on bridge piers, break up meander patterns, and reduce erosion of approach roads. Design techniques are reviewed in Neill (1973).

Dikes (sometimes called spurs) are in-river structures that extend from the river bank into the flow field. They are designed to direct or confine the flow to prevent bank erosion, realign a river reach, or increase channel flow depth (Petersen, 1986). Such structures are generally designed using physical model studies because of the difficulty in predicting impact of dikes on a particular reach of river. Local scour may be a problem at flow concentrations and local eddies which form at the end of the dike (Farraday and Charleton, 1983). Spacing and design factors are discussed by Petersen (1986) and by Farraday and Charleton (1983).

Revetments are structures designed to protect stream banks from erosion. The operating principle is the placement of a shear-resistant material between the flow field and the bank to be protected. Riprap is one of the most common types of revetment. Design procedures for riprap are widely available (Chow, 1959, presents a method using tractive force for design.). If the stones are sufficiently large, riprap can improve fish habitat (Smith and Maderak, 1993). In addition, riprap is easily constructed, adjusts to the stream bank, is durable, and if properly designed, is relatively maintenance free. However, riprap is still subject to local scour and if not properly embedded in the stream bed may fail by sliding down the bank.

Other forms of revetment are articulated concrete, gabions, interlocking blocks, and bagged concrete. Design of these appurtenances is widely documented (Petersen, 1986).

Vegetation can also be used as bank protection (Smith and Maderak, 1993, Gray and Leiser, 1977). Shrubs such as willows, serviceberry, buffalo berry, and currant were effective in reducing velocity near the bank. This effectively reduced the boundary shear stress, resulting in less potential for erosion. In addition, the intertwined root systems of these shrubs served to reduce the potential for soil movement.

Drop Structures

A drop structures are hydraulic devices used to lower channel bottom elevation over a short distance and dissipate the specific energy added as a result of the change in elevation (Corry *et al.*, 1975). Numerous types of drop structures have been developed, and design practices are reviewed in Taggart *et al.* (1987). Design guidelines are presented by Denver Regional Council of Governments (DRCOG, 1961).

River/Stream Analysis

In determining bridge and culvert designs, the designer analyzes the river/stream. Traditionally, these analyses were limited to the hydrology and hydraulics of the stream system. However, streams are conveyors of significant quantities of sediment, in addition to the runoff (Leopold and Maddock, 1953). Therefore, changes in the flow dynamics of the stream, in response to changes effected by installation of bridges and culverts, may result in significant changes to the sediment mobilization and transport characteristics of the stream. This is, inherently, the bridge scour problem. However, changes in sediment mobilization and transport may result in aggradation of the stream bed, not necessarily degradation (Keefer, *et al.*, 1980).

Therefore, an expanded approach to the analysis of river/stream systems is required, if problems such as degradation and aggradation are to be addressed. One method for classifying streams is the Rosgen method (Rosgen, 1985, 1994). The application of this system uses physical characteristics of the stream reach to arrive at a classification. Its advantage over other systems is that it identifies components of stream morphology not in equilibrium with other attributes of the channel and flood plain.

Design Approaches

Channel rehabilitation methods can be either active or passive (Gordon *et al.*, 1995). Rehabilitation is termed passive if the disturbance is corrected and the channel is left to re-establish itself. Active methods are those in which repairs are applied to the channel.

A design approach is suggested by Ontario Ministry of Natural Resources (1994). The perspective is from the watershed level down to the river reach level. Some aspects of the procedure (referred to as the Ontario approach) will not apply to TxDOT requirements. However, many of the concepts presented in the reference can be used by TxDOT for analysis and design of channel modifications. An overview of the steps in the Ontario approach is:

1. Define objectives for design,
2. Define existing channel or stream conditions,
3. Define expected natural regime,
4. Identify inconsistencies,
5. Define design parameters for unconstrained design,
6. Identify constraints,
7. Identify tradeoffs,
8. Develop final design parameters, and
9. Evaluate design.

Three fundamental objectives were defined: 1) construction of a new channel where no defined channel exists, 2) maintenance or rehabilitation of an existing channel not subject to changes in hydrologic flow regime, and 3) reconstruction or adaptation of an existing channel subject to changes in hydrologic flow regime. In general, the third objective seems applicable to TxDOT design activities.

Objectives are further subdivided. Potential uses for the stream and design objectives include aquatic and semi-aquatic habitat, recreation, aesthetic use, drainage, protection from floods, water supply, power generation, and others.

Application of the Ontario approach suggests a matrix to combine needs, uses, and objectives with channel parameters to aid determination of important design parameters. Specification of existing conditions involves classification of physical characteristics of the stream. The Ontario approach uses the Rosgen classification system (Rosgen 1985, 1994).

The message of the Ontario approach is twofold: 1) Streams and rivers are dynamic entities. It is imperative to understand which components are in equilibrium and which components are dynamic. A designer cannot consider only a single point on a stream or river system. Conditions upstream and downstream from the design point impact stream characteristics at the design point. Furthermore, changes at a given point on a stream can effect substantial changes both upstream and downstream from that point. Without consideration of these conditions and their impact on the stream at the design point, it is unlikely that a resilient design can be constructed. 2) Streams and rivers are not simply conveyors of water; significant amounts of sediment are also transported. Therefore, consideration of flow hydraulics alone is insufficient to arrive at proper channel designs; sediment transport may be equally, or perhaps more important for development of reasonable bridge and culvert designs. The potential for degradation and aggradation must be considered as well. The detachment and transport of sediment is a watershed process. Therefore, as suggested by the Ontario approach, consideration of the entire watershed may be required for development of reasonable hydraulic designs.

Case Studies

A limited number of case studies have been published. Cotton and Ports (1988) reported the relocation of a three-mile reach of the Salt River as a result of highway construction. The approach taken by the designer was to analyze river behavior using historical aerial photographs topographic maps to establish grade, channel geometry, and channel motion. Additional measurements of bed composition established scour potential.

A conference was conducted in 1994 (Shrubsole, 1994) to promote development of guidelines for design of "natural" channel system. The term "natural" was applied to denote designed and constructed channel systems similar in appearance and function to those that might develop under unmodified, or natural, conditions. This development is immature and significant changes can be expected as additional research and experience is accrued.

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CHAPTER III

CHANNEL MODIFICATION MITIGATIN BIBLIOGRAPHY

STREAM CHANNEL HYDRAULICS

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Abstracts in the following section were prepared from articles and reports that discuss topics concerning changes in channels resulting from construction of bridges and culverts and from changes in watersheds that impact stream flows and channel conditions in the affected watershed. The abstracts can be grouped roughly into the categories concerning impacts of channel modification or relocation caused by construction of bridges or culverts on watershed hydrology and morphological features of the channel and the mitigation of these impacts by stabilization measures that can be implemented. Scour, its occurrence, extent, and mitigation were the subject of most of the articles. Problems at both culverts and bridges were addressed. Several publications in the group can be classified in more than one category, which is to be expected on the basis of the topic areas and their inter-relationships. The selections range from 1934 to 1995 with related study areas from all over the nation; this is appropriate because of the climatic regimes encountered in Texas. The introductory section gives an overview of the abstracts by topic to help readers evaluate their needs prior to reviewing the abstracts. Sanders (1980) has written a manual that serves as a reference for hydrologic studies in conjunction with highway engineering practice. This is a good overview and provides information needed to assess conditions at highway crossings of water channels. Another reference that helps in the understanding of flood studies, which are important in the evaluation of highway water crossings, is the U.S. Department of Interior's Bureau of Reclamation 1965 publication entitled *Design of Small Dams*. This manual has much information pertinent in the design of embankments and structures at highway water crossings.

SCOUR PROBLEMS AT CULVERTS

The large number of problems associated with the numerous water crossings serviced by culverts has generated studies examining scour downstream. The following four studies concerning scour at culvert outlets were performed at Colorado State University. Smith (1957) examined the kinetic energy drop at outlets of circular culverts and its impact upon bed material. The knowledge was then used to determine the amount of rock riprap needed for channel protection. Opie (1967) examined the relationship of bed material and discharge to the size and geometry of scour holes from various experimental sites. M. A. Stephens (1969) examined outlet basins formed of rock riprap downstream of circular culvert outlet basins. The relationship between culvert flows and their impacts on the design of the basin were analyzed. Chen (1970) used dimensional analysis to represent scour phenomena at rectangular culvert outlets and compared scour phenomena for rectangular and circular culverts.

Simmons, Stevens, M. A., and Watts (1970) examined the hydraulics of rigid basins and basins stabilized with rock riprap below culvert outlets. The study results can be used to design energy dissipaters. Simmons and Stevens (1971) examine the scour mechanism and demonstrate analysis procedures necessary to design control works using rock riprap around culvert outlets. Spence and Larock (1979) illustrate an interactive computer-aided design program for culverts for use by experienced engineers, which allows the selection of a culvert that is able to pass the prescribed flow without excessive scour downstream and too much backwater upstream. Abt et al. (1983) examines the development of aggraded mounds downstream of a culvert outlet. The approximate area of the scour influence was related to culvert diameter and discharge intensity. Ehlers (1984) examines the use of a gabion straight drop structure and shows flow profiles that must be developed to determine the length of apron necessary to prevent tailwater scour.

SCOUR PROBLEMS AT BRIDGES

The size of bridge openings and the placement and sizing of bridge piers with all their impacts on both backwater and scour conditions at the highway crossing have generated studies. Yarnell (1934) examined the shape and length of piers upon backwater heights at the channel crossing. The amount of obstruction that the pier causes depends upon the channel flow, the shape of the pier nose and tail, the percentage of channel contraction caused by the pier, and the alignment of the pier with the thalweg of the stream. Corry et al. (1975) set forth a procedure to evaluate the capability of a channel to withstand erosive forces and scour potentials at highway crossings under superimposed flow conditions. The erosion hazard assessment will then aid the selection and design of an energy dissipater. Brice and Blodgett (1978) in a two volume study examined 224 bridge sites in the U.S. and Canada and developed guidelines to assist in selecting measures that can be used to reduce bridge losses attributable to scour and bank erosion. Performance ratings are given for various add on measures as well as bridge design measures.

Data obtained on scour around select bridges in Arkansas lead to the development of an equation predicting scour around bridges (Southard 1992). The Froelich equation was found to best represent the data. However, the mixed results obtained using predictive equations have led to collecting scour data during floods. Scour depths measured during flood are site and flow specific and more complex than laboratory studies indicate. Anderson (1966) presents a case history of a bridge failure April 1, 1962, due to erosion downstream of one pier on the I-29 bridge crossing the Big Sioux River upstream of its confluence with the Missouri River. The failure was the result of cascade of events that impacted the failure event.

Searcy (1967) reviews the design, material selection, construction principles, and installation of rock riprap. Simons and Lewis (1971) present design techniques for rock riprap protection at bridge crossings. Hydraulic properties at the crossing serve as a guide for size of material used in rock riprap. Blodgett (1986) produced two volumes concerned with riprap design near hydraulic structures. Volume 1 examines the hydraulic and channel properties of streams from several hundred sites to assist in preparing rock riprap bank protection. The most stable channel characteristics for a given discharge are slope, maximum depth, and hydraulic radius. Volume 2 uses data from 26 field sites to evaluate 7 procedures used in the design of rock riprap. After a review of field data and design procedures, it was found that estimates of hydraulic forces acting on the boundary based on the flow velocity were more reliable than to use shear stresses in the evaluation. Success of riprap is based on the appropriate procedures for selecting stone size as well as the reliability of estimated hydraulic and channel factors applicable to the site.

BACKWATER EFFECTS AT BRIDGE OPENINGS

Bradley (1959) examined backwater impacts based on bridge length and clearance using field measurement and hydraulic models. Using field research, impacts of bridges on upstream and downstream flow are discussed in an updated version (Bradley 1973). Additionally, information on partially inundated superstructures, supercritical flows at the bridge, and proportioning of spur dikes at bridge abutments is presented. Liu et al. (1957) reported on an experimental study using flumes which evaluated the effects of piers and abutments on backwater in a prismatic channel. Background data on flow through constrictions are presented. Davidian et al. (1962) examined flow patterns at bridges with two to seven openings in a laboratory setting. The study was directed toward apportioning a given discharge among several openings, computing discharge through the openings, and predicting the backwater caused by the constrictions. The division of flow was related to the relative area of each opening and the relative velocity in the channel upstream from each opening. Neill (1964) published a review of riverbed scour for engineers and served as editor (1973) for a guide to bridge hydraulics. The guide includes an in-depth analysis of the hydraulic design of bridges, including backwater and scour problems. Shearman et al. (1986) describes the use of a digital model for water-surface profile computations through bridge openings that incorporates developments in bridge backwater analysis and recognizes bridge geometry variations. Pressure flow situations are computed using FHA techniques.

IMPACTS RESULTING FROM CHANNEL RELOCATION

In the construction of highway crossings, the water channel of a natural system has often been relocated as part of the design and construction process. Babcock (1986) reports on results of a stream relocation that occurred in the construction of I-70 west of Denver. A project goal was to equal or improve fishery habitat in the new channel over that of the natural channel. Even with the 25-year flood occurring within 2 years of project completion which resulted in 75 percent ineffectiveness of the installed habitat structures, the fishery improved because of the design techniques that were implemented in the construction of the new channel. Other articles that were pertinent to river crossing situations where channel relocation might be employed were examined. Bowles et al. (1985) examined the field and analysis procedures necessary to prepare a diversion design that would minimize impacts on downstream channel stability. The two diversion types analyzed were (1) the impoundment of the flow and use of pump-pipeline system to carry the decanted flow to the channel downstream and (2) the placement of a training dike to divert flow to a diversion channel. Robins and Simon (1982) examined the impacts of channel modifications caused by human activities on river systems that have contributed to bridge failures in Tennessee. Modifications to the channel in conjunction with other land use changes on the watershed instigated downcutting of the channel, headward erosion, accelerated scour, bank instabilities, and downstream aggradation. Changes in gradient caused by channel straightening caused more channel stability problems than channel clearing or dredging. Response times for attaining equilibrium channel slopes were found to be a function of the magnitude and extent of the imposed modification.

CHANNEL MORPHOLOGY CHANGE AND RESTORATION

Changes in stream parameters that occur anywhere in the drainage basin can instigate movement from one equilibrium to a new state point that may take years to reach and may initiate changes that move both upstream and downstream from the point where the equilibrium was disturbed. Construction of highway crossings may initiate the change from one equilibrium point to another. Also, the highway crossing may feel the impacts of changes that were initiated at some other point in the watershed. These impacts from other disturbance points in the drainage basin may damage the bridge crossing even though the best design procedures were used for the water crossing facility. Be aware that the river over which highway crossings are being built may be subject to a change situation that is already in force or one about to be instigated from another point in the drainage basin that is about to initiate a channel disturbance. Articles that examine the changes in channel morphology as well as articles that evaluated impacts on channels and channel properties from watershed activities were reviewed.

Barnes (1967) provides descriptive data and photographs for 50 channels where the roughness coefficient has been evaluated. The examples selected show a wide range of channel conditions. Gregory and McCarty (1986) developed equations to estimate the maximum allowable velocity and permissible shear stress for vegetative channels using slope of the channel, maximum allowable velocity or shear stress for bare soil conditions and fraction of surface cover.

Campbell and Sidle (1984) use data from 80 small (0.54 km2 to 27.45 km2) watersheds in 6 physiographic regions to develop equations that can predict peak flows for use in culvert design on forest roads. Data on annual peak flow from gauging stations with more than 20 years of records were analyzed using 4 flood frequency distributions. The log-Pearson type III was suitable for use in all regions of Oregon. Drainage basin size, mean basin elevation, and mean annual precipitation were significant in predicting variations in flood peaks. Piel et al. (1988)

evaluate the peak flow capacity of 128 stream crossing culverts in the Central Oregon coast range and compared the results to current design guidelines. Over 40 percent of the culverts were unable to pass the 25-year peak flow at a headwater to diameter ratio of 1 to 1. Installing the next larger pipe size at an additional cost of 14 percent would have allowed nearly all the culverts in the study to pass the 25-year peak. Keller and Capelli (1992) report on the 1992 Ventura flood and show that there are limitations to flood flow modeling. Some of these are avoidable. The Army Corps of Engineers (1994) has published a manual to help determine channel instability and sedimentation effects on flood control projects. Assumptions are made that the plan, cross section, and longitudinal profile of the channel are economically maintainable over the life of the project.

Wolman and Brush (1961) in laboratory flume studies evaluated the factors controlling size and shape of stream channels in coarse, noncohesive sands. The flow, slope, sediment load, and bed and bank material could be varied independently. The experiments were run until a stable equilibrium was obtained in which the channel width, water surface slope, and sediment load became constant. Detention storage in specific situations has increased peak rates of runoff (Hawley et al. 1981). As a result of increased flow rates, an analysis should be performed using a simple peak discharge equation.

Keefer et al. (1980) examine the impacts of gradation problems on alluvial rivers caused by human activities. Emphasis is made that human activities are responsible for the most severe cases of channel aggradation and degradation. A simple hydraulic analysis is presented at sites where these processes are suspected to show how to predict the limiting slope of a gradient change based on critical shear stress of the bed material. More complex procedures use differential equations. The best regional indicator of aggradation or degradation is a sediment yield map of the area of interest since high sediment yield correlates with erodibility.

Nunnally and Keeler (1979) examine stream restoration methods that trade off losses in channel efficiency (channelization) for a more stable channel morphology and better aquatic and fluvial systems. They state that channel restoration is one-tenth of the cost of stream channelization. Stream adjustments occur in response to human-induced changes on the drainage basin (Heede 1986). If humans work with the ongoing change process, then success will be attainable with lower effort and less cost. Local base level change is one of the most influential channel changes that may be reflected throughout the basin and thus prevention of such change is a cost-effective measure. Other channel treatments are presented. Beschata and Platts (1986) show how to use unit stream power, the time-rate loss of potential energy per unit mass of water, to alter man-made changes in channel morphological features (pools, riffles, and stream banks). Using this parameter can help to restore the stream to its previous state by adding stream obstructions, increasing flow resistance (vegetation on banks), and by increasing channel sinuosity. Petersen (1986) outlines a variety of methods such as stream bed control structures, channel alinement, cut-offs, and channel training works such as revetments, dikes, and gabions used to correct hydraulic problems in rivers. Using data obtained in a flume study, Cherry and Beschata (1989) found that coarse woody debris (fallen trees, logs, groups of logs, ect.) placed either perpendicular to the flow or oriented in the downstream direction require less anchoring and promote channel stability. These materials removed under previous channel maintenance guidelines are beneficial to fish habitat and an important influence on sediment routing in the channel. Gully control structures installed on the Zuni reservation in New Mexico were evaluated as to their erosion control effectiveness by Gellis et al. (1995). Structures of either earth or rock were either breached or significantly silted. Sixty-five percent of the rock and brush structures were in good condition as a result of proper spacing measures being used in their design. In addition to the proper structures being installed, erosion control measures utilized in the drainage basin should be implemented.

Schumm et al. (1984) studied the formation, hydraulics, progression, and control of incised channels. The risks to manmade structures such as bridges are noted. Harvey and Watson (1986) examined the factors (at site or extrinsic to the system) that initiate downcutting in a channel. Progression of this phenomena causes interdependent changes of channel slope and cross sectional area (channel widening and bank failure) until a new state of dynamic equilibrium with the imposed discharge and sediment load is achieved. Restoration of incised channels generally involved control of discharge and control of channel grade after a model of channel evolution is formulated. Shields et al (1995) discussed the rehabilitation of 15 incised watersheds that exhibited erosion and sedimentation problems in northern Mississippi. Rehabilitation measures are selected by using a subjective integration of hydraulic and geotechnical stability analyses. Problems in analyzing and rehabilitating channels are set forth. Application of the idealized channel evolution model to specific watersheds is not straightforward. Predicting the success of installed rehabilitation measures in the channel reach and watershed land use changes is uncertain. The goal of channel rehabilitation is well vegetated corridors along sinuous streams.

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Abt, S.R., J.F. Ruff, and C. Mendoza, 1983. Mound Formation at Culvert Outlets. Water Resources Bulletin 19(4):571-576.
The local scour process near a culvert outlet is accompanied by the formation of an aggraded mound downstream of the scour area. This investigation devises relationships depicting the formation, growth, and estimated maximum dimensions of a mound in a uniformly graded sand material due to clear water scour. The maximum dimensions of the mound were correlated to the discharge intensity $(Qg^{-.5}D^{-2.5})$, the maximum dimesions of the scour hole, time, and tail water elevation. The concept of an approximate area of scour influence was developed relating the mound width, scour hole length, and mound length as a function of the culvert diameter and discharge intensity. Tail water effects upon mound formation were noted; the greater the tail water elevation, the higher the mound.

Anderson, A.G., 1966. The Hydraulic Design of Bridges for River Crossings: A Case History. Prepared for Presentation at the 46th Annual Meeting of the Highway Research Board, Washington D.C.
This report is a case history analysis of a bridge failure on I-29 in Minnesota.

Babcock, W.H., 1986. Tenmile Creek: A Study of Stream Relocation. Water Resources Bulletin 22(3):405-415.
This study is a study of stream relocation during the construction of Interstate 70 west of Denver. One of the main focuses of this project was to provide a fish habitat of equal or improved quality. A 4 percent chance flood occurred 2 years after project completion, resulting in nearly 75 percent ineffectiveness of habitat structures. Even with this setback the number of fish in the study area increased and aquatic invertebrate populations remained similar. Biologists of the Division of Wildlife made recommendations on stream improvement:1) Construct as narrow a channel as possible to concentrate the water in periods of low flow, 2) Construct steep vertical banks to reduce the clearing width and to increase the possibility of excellent trout habitat -- undercut banks, and 3) Construct and place several types of habitat-creating structures and build bridges so they would not be a barrier to fish migration. The main channel-habitat structures used were current deflectors, check dams, and random rock replacement.

Barnes, B.H., Jr., 1967. Roughness Characteristics of Natural Channels. Geological Survey Water-Supply Paper No. 1849, U.S. Government Printing Office, Washington, D.C.
Color photographs and descriptive data are presented for 50 stream channels for which roughness coefficients have been determined. In the absence of a satisfactory quantitative procedure for determining roughness coefficients, this evaluation remains chiefly an art. The ability to determine roughness coefficients must be developed through experience. One means of gaining this experience is by examining and becoming aquainted with the appearance of some typical

channels whose roughness coefficients are known. The photographs and data contained in this report represent a wide range of channel conditions.

Beschta, R.L. and W.L. Platts, 1986. Morphological Features of Small Streams. Water Resources Bulletin 22(3):369-379.
"Where channel morphology is modified or structural features are added, stream dynamics and energy dissipation need to be considered." Unit stream power, the time-rate loss of potential energy per unit mass of water, can be reduced by adding stream obstructions, increasing channel sinuosity, or increasing flow resistance with large roughness elements such as woody root systems, logs, boulders, or bedrock. Morphological features examined here include: pools, riffles, bed material, and stream banks. The changes made result in changes in flow regime, sediment availability, and in stream structures. These changes manifest themselves in changes in (1) longitudinal profile, (2) channel sinuosity, (3) roughness of bed or bank, and (4) hydraulic radius. "Altering the cross-section shape or hydraulic radius (such as widening a channel by adding an in-stream structure) may induce subsequent changes in channel longitudinal profile, sinuosity, or roughness." All of these factors often act concurrently resulting in a difficult prediction of future response. The authors believe that streamside vegetation is the most important of the constraints upon channel morphology.

Blogdett, J.C., 1986. Rock Riprap Design for Protection of Stream Channels Near Highway Structures, Vol. 1 Hydraulic Characteristics of Open Channels. USDI, U.S. Geological Survey Water Resources Investigations Report 86-4127, Sacramento, California, 60 pp.
The hydraulic and channel properties of streams are outlined, based on several hundred sites. Streamflow and geomorphic data have been collected and developed to indicate the range in hydraulic factors typical of open channels, to assist design, maintenance, and construction engineers in preparing rock riprap bank protection. The most stable channel characteristics for a given discharge are slope, maximum depth, and hydraulic radius.

Blogdett, J.C., 1986. Rock Riprap Design for Protection of Stream Channels Near Highway Structures, Vol. 2 Evaluation of Riprap Design Procedures. USDI, U.S. Geological Survey Water Resources Investigations Report 86-4127, Sacramento, California, 95 pp.
Seven procedures now being used for the design of rock riprap installations were evaluated using field data from 26 sites. Four basic types of riprap failures were identified: particle erosion, translational slide, modified slump, and slump. Factors associated with riprap failure include stone size, bank side slope, size gradation, thickness, insufficient toe or end wall, failure of the bank material, overtopping during floods, and geomorphic changes in the channel. A review of field data and the design procedures suggest estimates of hydraulic forces acting on the boundary that are based on flow velocity rather than shear stress are more reliable. Several adjustments for local conditions such as channel curvature,

super-elevation, or boundary roughness may be unwarranted in view of the difficulty in estimating critical hydraulic forces for which the riprap is to be designed. Success of riprap is related not only to the appropriate procedure for selecting stone size, but also to reliability of estimated hydraulic and channel factors applicable to the site.

Bowles, D.S., J.L. Grant, W.E. Humphries, and A.P. O'Hayre, 1985. Design and Impact Analysis for Diversion at Coal Creek Mine. Water Resources Bulletin 21(6):995-1003.
This study outlines the field and analysis procedures necessary to prepare the diversion design and impact evaluation for the design of a diversion system design with the aim of minimizing the impacts on downstream stability. Two diversions were carried out, 1) flow was impounded by a small dam and decanted by a small pump through a pipeline into the stream at the location of the second diversion, 2) a training dike was placed across the stream channel to divert flows to a diversion channel. Gravity flow along the diversion channel will deliver water to a playa lake that will be converted into a detention basin by placing a small dam across its south end. Flows up to the magnitude of the 24-hour 2-year peak flow will be passed directly through the detention basin with little attenuation of flow rates. In the case of less frequent events, water will be stored in the detention basin to prevent velocities in the downstream reaches of the system from exceeding the maximum permissible velocity above which scouring will occur. By passing the more frequent events directly through the detention basin, evaporation and seepage losses from water stored in the basin will be eliminated for all but the less frequent, more severe events.

Bradley, J.N., 1959. The Use of Backwater in the Design of Bridge Waterways. Public Roads, Vol. 30, No. 10, Division of Hydraulic Research Bureau of Public Roads.
What proportion of existing bridges are over- or under-designed from a standpoint of length and clearance? This article includes one variable in the design of bridge waterways --backwater computation. The data presented here are based on both experimental backwater studies using hydraulic models and field measurements.

Bradley, J.N., 1973. Hydraulics of Bridge Waterways, Hydraulic Design Series No. 1. U.S. Department of Transportation, Federal Highway Administration, Hydraulics Branch Bridge Division Office of Engineering, Washington D.C., 111 pp.
This study is of great importance to the study we are undertaking here, and special attention should be taken with its contents. As noted in the Forward and Preface, this study was undertaken by request to revise the first edition, and thus contains some updated material. This work also concentrates more upon the effects of bridges on the upstream and downstream flow. Also contained here and not in the previous work are chapters on partially inundated superstructures, the proportioning of spur dikes at bridge abutments, and supercritical flow under a bridge, each with examples. The recent field research has added considerably to

the information contained in the study. Also of interest in this manuscript is the study of backwater at bridge crossings.

Brice, J.C., and J.C. Blodgett, 1978. Coutermeasures for Hydraulic Problems at Bridges, Volume 1 - Analysis and Assessment, Volume 2 - Case Histories for Sites 1-283. U.S. Gelogical Survey, Water Resources Report Nos. FHWA-RD-78-162, and FHWA-RD-78-163.
Guidelines have been developed to assist design, maintenance, and construction engineers in selecting measures that can be used to reduce bridge losses attributable to scour and bank erosion. These guidelines are based on case histories of 224 bridge sites in the U.S. and Canada, on interviews with bridge engineers in 34 states, and on a survey of published work on countermeasures. Performance ratings are given for rigid and flexible revetment, for flow control measures (spurs, dikes, spur dikes, check dams, and jack fields), and for measures incorporated into the bridge.

Campbell, A.J. and R.C. Sidle, 1984. Prediction of Peak Flows on Small Watersheds in Oregon for Use in Culvert Design. Water Resources Bulletin 22(1):9-14.
Using data from 80 Oregon watersheds ranging in size from 0.54 km^2 to 27.45 km^2, equations were developed to predict peak flows for use in culvert design on forest roads. After dividing Oregon into six physiographic regions, annual peak flow data from gauging stations with more than 20 years of record were analyzed using four different flood frequency distributions: Type 1 extremal, two parameter-log normal, three parameter-log normal, and log-Pearson Type III. The log-Pearson Type III distribution was found to be suitable for use in all regions of Oregon, based on the Chi-square goodness-of-fit-test. Flood magnitudes with recurrence intervals of 10, 25, 50, and 100 years were related to physical and climactic characteristics of drainage basins by multiple regression. Drainage basin size was found to be the most important variable, with mean basin elevation and mean annual precipitation shown to also be significant in predicting variations in flood peaks. "Installation of a culvert that is larger than necessary results in needless expense, while under design may result in failure of the installation and damage to aquatic habitat downstream of the culvert site." The equations in this study are intended to be used with on-site information in the design of optimally sized culvert crossings for use on small forested watersheds.

Chen, Y.H., 1970. Scour at Outlets of Box Culverts. M.S. Thesis, Colorado State University, Fort Collins, Colorado.
This study is an outline for design criteria for riprapped stilling basins at outlets of rectangular culverts. Scour phenomena at rectangular culvert outlets are presented by means of dimensional analysis. Noted here is the effects of culverts on long downstream stretches from the culvert site, and the need for a rock riprap stilling basin for energy dissipation. Scour phenomena for rectangular and circular culverts are compared and discussed.

Cherry, J. and R.L. Beschta, 1989. Coarse Woody Debris and Channel Morphology: A Flume Study. Water Resources Bulletin 25(5):1031-1036.
"Recent research results have indicated that coarse woody debris (CWD) is generally beneficial to fish habitat and an important influence on sediment routing and channel morphology. Whereas only a few years ago woody debris was removed from streams because it was considered detrimental, individual logs, groups of logs, and other materials are currently being added to streams to modify fish habitat. Often, the hydraulic stability and function of these structural additions cannot be ascertained until they have undergone one or more periods of high flow. This flume study was conducted to observe local scour patterns and aggradation associated with individual pieces of CWD." Upstream orientations of simulated logs proved to cause flow disturbances resulting in large scour depths and increased potential for streambank erosion. A more stable position (with respect to streambank erosion) was found with log orientations downstream or perpendicular to the flow. Such orientations may require less anchoring for stability and are more often found in natural stream systems, thus downstream orientations may be desirable when CWD is added to streams for long-term improvement of aquatic habitat.

Corry, M.L., P.L. Thompson, F.J. Watts, J.S. Jones, and D.L. Richards, 1975. The Hydraulic Design of Energy Dissipators for Culverts and Channels. U.S. Department of Transportation, Federal Highway Administration, Hydraulic Engineering Circular No. 14.
The interception and concentration of flow at highway crossings inevitably results in an increased erosion potential. To protect the highway and adjacent areas, it is sometimes necessary to employ an energy dissipating device. These devices cover a wide range in complexity and cost. The particular type selected will depend on the assessment of the erosion hazard. This assessment includes determining the ability of the natural channel to withstand erosive forces and the scour potential represented by the superimposed flow conditions. The purpose of this circular is to aid in selecting and designing an energy dissipator that will meet the requirements indicated by an erosion hazard assessment.

Davidian, J., P.H. Carrigan, Jr., and J.Shen, 1962. Flow Through Openings in Width Constrictions. U.S. Geological Survey Water Supply Paper 1369-D, Washington, D.C., U.S. Government Printing Office, 32 pp.
A highway embankment across a stream channel may have one or several bridge openings. This is the report of the results from an investigation of flow patterns at width constrictions with two to seven openings. The laboratory experiments and analysis were directed toward developing methods for 1) computing discharge through multiple-opening constrictions, 2) apportioning a given total discharge among several openings, and 3) predicting the backwater curve caused by the constrictions. The division of flow among the openings was related to the relative area of each opening, and to the relative velocity in the channel immediately upstream from each opening. On the basis of these relationships, the boundaries of the flow channel approaching each opening were established. The head-

discharge and backwater characteristics of each opening were then analyzed separately. Once the boundaries of the separate flow channels have been established, it is shown that the relations of the characteristics are applicable to one opening constriction also.

Ehlers, B.E., 1984. The Stability of a Gabion Straight Drop Structure. M.S. Thesis, University of Arizona, Department of Civil Egineering.
This study examines the situations where a gabion straight drop structure operates adequately Flow profiles are developed dictating the length of apron necessary to decrease tailwater scour.

Gellis, A.C., A. Cheama, V. Laahty, and S. Lalio, 1995. Assessment of Gully-Control Structures in the Rio Nutria Watershed, Zuni Reservation, New Mexico. Water Resources Bulletin 31(4):633-646.
In the latter part of the 19th century and early 20th century, a major cycle of erosion, gullying, or arroyo cutting occurred in the southwestern U.S. This project was instituted to evaluate the effectiveness of erosion control structures on the Zuni Reservation in New Mexico. Structures of earth or rock, and rock and brush structures were found to be either breached or significantly silted. Sixty-five percent of the rock and brush structures were found in good condition; indications are that they are meeting their purposes of aggrading their channel. One reason for their success is that they meet the specifications of the spacing rule: $S = H_e /KG \cos a$ where S is the spacing (meters), H_e is the dam height (meters), G is the channel gradient (meters/meters), Cosa is the angle corresponding to the channel gradient, and K is a constant (for channel gradients less than or equal to 0.20, K is 0.3, and for gradients greater than 0.20, K is 0.5). In theory, upstream erosion control practices over time should reduce the amount of sediment delivered to the main channels and/or reduce the downstream delivery of the sediment. Means to this end include understanding arroyo evolution and proper spacing of structures. When the structures become silted, additional measures need to be taken to ensure that large flows are directed over the spillway. Other methods mentioned to reduce erosion consisted of livestock reduction and structural treatments such as plugging gullies, contour trenching gullies with earthen dams, channel shaping, road drainage, and vegetative seeding.

Gregory, J.M., and T.R. McCarty, 1986. Maximum Allowable Velocity Prediction for Vegetated Waterways. Transactions of the American Society of Agricultural Engineers, Vol. 29, No. 3.
Physically based equations were developed to estimate the maximum allowable velocity and permissible shear stress for vegetative channels. Input variables include fraction of vegetative cover at the soil surface, channel slope, and maximum allowable velocity or the maximum allowable shear stress for bare soil conditions.

Harvey, M.D. and C.C. Watson, 1986. Fluvial Processes and Morphological Thresholds in Incised Channel Restoration. Water Resources Bulletin 22(3):359-368.
Incised channels are those in which an imbalance between sediment transport capacity and sediment supply has resulted in degradation of their beds. Incised channels exist with their characteristic morphology because the eroding forces exerted by a concentrated flow of water that exceeds the resistance of the earth materials over which it flows. The development of an incised channels at a specific locations may depend on controls acting at that site or the upstream or downstream changes that effect the sites. In addition, the response can be the result of extrinsic controls that are imposed on the system such as climactic fluctuations, base level changes, land use changes, or channel modification. If the aforementioned effects initiate degradation that cause a critical bank-height threshold to be surpassed, which is dependent upon the geotechnical properties of the bank materials, then bank failure and channel widening follow. Interdependent changes of channel slope and cross-sectional area occur until a new state of dynamic equilibrium with the imposed discharge and sediment load is attained. With an understanding of these geomorphic adjustments, a model of channel evolution can be formulated. Three approaches to design of rehabilitation methods are possible: geomorphic, engineering, and rational. The rational approach, which involves a combination of the other two, is based on the channel evolution model generally involving control of grade and/or a control of discharge. This study concentrates most of its resources to the study of incised channels due to channelization. There is, however, an adequate outline of the rational approach to channel restoration and its marriage of the engineering and geomorphic approaches.

Hawley, M.E., T.R. Bondelid, and R.H. McCuen, 1981. A Planning Method for Evaluating Downstream Effects of Detention Basins. Water Resources Bulletin, 17(5)806-813.
Recent research has indicated that under certain circumstances detention storage can actually cause increases in peak discharge rates. Because of the potential for detrimental downstream effects of these peak discharge rates, the effects of detention basins on downstream reaches needs to be evaluated. An inexpensive method that is easy to apply and that would indicate whether a detailed analysis of downstream impacts is necessary, thus possibly decreasing design costs, is presented here. This planning method does not involve a large data base or a computer. The discharge coordinates are estimated using a simple peak discharge equation.

Heede, B.H., 1986. Designing for Dynamic Equilibrium in Streams. Water Resources Bulletin 22(3):351-357.
"Streams are dynamic systems, so steady state does not exist for any appreciable period of time. Streams in dynamic equilibrium respond quickly to change, regaining a new equilibrium. From the response system it follows that there is a causative reason why a stream meanders or degrades or aggrades its

bed. These actions represent adjustment processes. If humans interfere with them, other adjustments will be initiated. In contrast, if humans work with the ongoing processes, success will be attainable with less efforts and at a lower cost. Local base level change represents one of the most influential channel changes, especially lowering of this level. Loss of base level may cause degradation throughout a stream network, because the main system is the base level for all its tributaries. Often, degradation causes bank instability and lowering of streamside water tables that, in turn, endanger the riparian ecosystem. Judging from check dam systems, a rise of the local base level does not raise the bed throughout a stream or network; instead, aggradation stops at a given distance. Preventing local base level changes of a stream network, therefore, is a cost-effective measure. Examples are presented of treatments causing new critical situations and measures to correct them." This work, although some recommendations are made, has its strength in the seemingly simple notion of a stream as a dynamic system seeking equilibrium. From this belief come many of the treatments of channels considered here. As such, many works could be aided in following this approach.

Keefer, T.N., R.S. McQuivey, and D.B. Simons, 1980. Stream Channel Aggradation and Degradation: Causes and Consequences to Highways. U.S. Department of Transportation, Federal Highway Administration Report No. FHWA/RD-80/038, 86 pp.

"Aggradation and degradation are long-term changes in stream channel elevation. The effects of gradation changes are not the same as local scour or erosion because they extend greater distances along the stream-bed. Degradation is a more common problem than aggradation and in general, has a more severe impact on highway crossings. Although gradation changes do occur naturally, human activities are responsible for the most severe cases. Channel alteration, stream-bed mining, and the construction of dams and control structures are the major causes of gradation problems. Virtually every river in the U.S., which flows on an alluvial bed, has a potential for gradation change. The prevalence of human activities as chief cause of gradation changes means many rivers suffer to some degree. The best regional indicator of degradation or aggradation potential is a sediment yield map for the U.S. or areas of interest because high sediment yields correlate with erodibility. To aid in the anticipation of gradation changes the highway engineer should be aware of the principles of geomorphology. The simplest hydraulic analysis procedures predict the limiting slope of a gradient change based on critical shear stress of the bed material. The methods can be applied to any site where degradation or aggradation are suspected. The most complex techniques use a computer solution of differential equations. These techniques are more expensive and are probably applicable only for a new bridge where gradation problems are anticipated using simple hydraulic and geomorphic methods." Some of the conclusions reached here include 1) gradation problems are a significant cause of maintenance problems at highway crossings, 2) the anticipation of gradation problems begins with an understanding of geomorphology, 3) simpler analysis procedures often times

should be chosen rather than the costlier mathematical models, 4) bridges in gradation sensitive areas should be inspected annually, and 5) little practical knowledge exists concerning appropriate remedial measures for gradation problems.

Keller, E.A. and M.H. Capelli, 1992. Ventura River Flood of February 1992: A Lesson Ignored? Water Resources Bulletin 28(5):813-832.
This work points out that there are limitations to flood-modeling methodologies. The effects of this effort can sometimes be disastrous but oftentimes avoidable.

Liu, H.K., J.N. Bradley, and E.J. Plate, 1957. Backwater Effects of Piers and Abutments. Civil Engineering Section, Colorado State University, Fort Collins, CO, US Dept. of Commerce, Bureau of Public Roads, CER57HKL10, 364 pp.
The purpose of this study was to determine the maximum height of backwater caused by a given local constriction in an otherwise prismatic channel. The experiments were conducted in flumes with various crossing conditions. The introduction sectiondiscusses the effects of a bridge on the stream or river which it spans. In Chapter III, the basic principles of open channel flow through constrictions is discussed extensively. In Chapter VI, the method of analysis of width constrictions is less accurate, but is easier to use than the prior in-depth analysis of different width constrictions. Although this work was published in 1957, much of the information contained here is of value in both qualitative and quantitative analyses of piers and abutments.

Neill, C.R. (Editor), 1973. Guide to Bridge Hydraulics. Roads and Transportation Association of Canada, University of Toronto Press.
This, as the name states, is a guide to bridge hydraulics. It is over a hundred pages in length and includes an in-depth analysis of hydraulic design of bridges including investigation of backwater and scour problems.

Nunnally, N.R. and E.A. Keeler, 1979. Use of Fluvial Processes to Minimize the Adverse Effects of Stream Channelization. Water Resources Research Institute, University of North Carolina, Report No. 144.
Compared to channelization, stream restoration involves trading off some losses in flow efficiency for a more stable channel morphology and significantly better aquatic and fluvial ecosystems. Stream restoration is accomplished by removing debris jams and providing fairly uniform channel cross-sections and banks, and stabilizing banks with vegetation and riprap where necessary. Economically, the cost of channel restoration is one-tenth of the cost of channelization.

Opie, T.R., 1967. Scour at Culvert Outlets. M.S. Thesis, Colorado State University, Fort Collins, Colorado.
The results of experiments to determine the size and geometry of scour holes in flat, loose rock beds at culvert outlets are given. From a dimensional analysis, the depth of scour at a culvert outlet is related to the discharge and bed material

characteristics. Also included are design examples, applying the design curves found here. Noteworthy is the fact that these design curves have a limited applicability due to the limits of this, and all experimental procedures.

Petersen, M.S., 1986. River Engineering, Chp. 7: Stabilization and Rectification of Rivers. Prentice-Hall, New Jersey, pp.149-224.
This chapter is a manual of sorts as to what can be done to rectify hydraulic or other problems in streams and rivers. It includes discussions of alignment, revetments, dikes, gabions, other channel protection measures, cost-analysis, cut-offs, streambed control structures, and various hydraulic models for river engineering.

Piehl, B.T., M.R. Pyles, and R.L. Beschta, 1988. Flow Capacity of Culverts on Oregon Coast Range Forest Roads. Water Resources Bulletin 24(3):631-637.
One hundred twenty-eight stream crossing culverts in the central Oregon coast range were evaluated for peak flow capacity and were compared with current design guidelines. Their ability to pass the 25-year peak flow and their maximum flow capacity were determined. Over 40 percent of the culverts were unable to pass the 25-year peak flow at a headwater to diameter ratio of 1. About 17 percent could not pass the 25-year peak flow without overtopping the roadfill. Installing the next larger pipe size at an additional cost of about 14 percent would have allowed nearly all these culverts to pass the 25-year peak flow. Culvert capacity varied with ownership and watershed size. This paper also includes some basic guidelines and common-sense practices for culvert design, including analysis with woody debris plugging of culverts.

Ree, W.O., and V.J. Palmer, 1949. Flow of Water in Channels Protected by Vegetative Linings. USDA Soil Conservation Service, Division of Drainage and Water Control, Technical Bulletin No. 967, February, 115 pp.
This work is concerned with the effects of vegetal linings on the capacity and stability of small channels. The study concentrated on plant species primarily adapted to the Southeastern and South Central States.

Robbins, C.H.,and A. Simon, 1982. Man-Induced Channel Adjustments in Tennessee Streams. USDI Geological Survey Open-File Report 83-43, Lakewood, Colorado, 128 pp.
Channel modifications in Tennessee, particularly in the western part, have led to large-scale instabilities in channelized rivers and may have contributed to several bridge failures. These modifiactions, together with land-use practices, led to downcutting, headward erosion, downstream aggradation, accelerated scour, and bank instabilities. Changes in gradient by channel straightening caused more severe channel response than did dredging or clearing. Water surface slope was found to be the primary indicator of channel problems. Response times for the attainment of equilibrium channel slopes were found to be a function of the magnitude and extent of the imposed modidfication. Where the channels were

straightened by constructing cut-offs, slope adjustments (reduction) proceeded downstream and upstream imposing new profiles with lower gradients.

Sanders, T.G., 1980. Hydrology for Transportation Engineers. U.S. Department of Transportation, Federal Highway Administration Report No. FHWA-IP-80-1, Prepared by the Colorado State University Department of Civil Engineering.
This manual was developed in order to serve as a reference for hydrologic studies in conjunction with highway engineering practice. This work is noted here as source of reference for investigation of hydrologic problems facing the transportation engineer in this project. As a whole, this study is voluminous, nonetheless, a few chapters can be chosen for investigation. Three main components arise: 1) basic hydrology, 2) concepts of statistics [including flood frequency distribution and mean and low flow analysis], and 3) applications or problem solutions.

Schumm, S.A., M.D. Harvey, and C.C. Watson. 1984. Incised Channels: Morphology, Dynamics, and Control. Water Resources Publications, Littleton, Colorado.
This publication, as the name implies, is a study of incised channels, specifically how they are made, why they are made, how they work hydraulically, and possible measures on how to control them. This publication states the hazards that incised channels present to man-made structures such as bridges. The stated goals of this work are to: 1) determine the evolutionary sequences or stages of incised channel evolution, 2) develop criteria for the recognition of potentially unstable valley-floors and channels, 3) recognize the stage at which conservation methods will be most effective, 4) develop a philosophy or strategy of incised channel management that is based on geomorphic principles, and 5) to develop a methodology for rehabilitation of incised channels.

Searcy, J.K., 1967. Use of Riprap for Bank Protection. U.S. Department of Transportation, Bureau of Public Roads, Hydraulics Branch, Bridge Division, Office of Engineering and Operations, Washington D.C.
This work contains an exhaustive overview of installing rock riprap for bank protection including the design, materials to be used, and construction principles.

Shearman, J.O., W.H. Kirby, V.R. Schneider, and H.N. Flippo, 1986. Bridge Waterways Analysis Model. U.S. Department of Transportation, Federal Highway Administration, Research Report No. FHWA/RD-86/108, 112 pp.
This report describes WSPRO which is a digital model for water-surface profile computations. Profile computations for open channel flow are compatible with conventional techniques used in existing step-backwater analysis models. WSPRO incorporates several desirable features from existing models. Profile computations for free surface flow through bridges are based on relatively recent developments in bridge backwater analysis and recognize the influence of bridge geometry variations. Pressure flow situations (girders partially or fully inundated)

are computed using existing Federal Highway Administration techniques. Embankment overtopping flows, in conjunction with either free-surface or pressure flow through the bridge, can be computed. WSPRO is also capable of computing profiles at stream crossings with multiple openings (including culverts).

Shields, F.D., Jr., S.S. Knight, and C.M. Cooper, 1995. Rehabilitation of Watersheds with Incising Channels. Water Resources Bulletin 31(6):971-982.
This work is about rehabilitation of watersheds with erosion and sedimentation problems caused by incision. A study of 15 incised watersheds in northern Mississippi shows that water quality is generally adequate to support aquatic organisms, but physical conditions are poor. Rehabilitation measures, that are selected and laid out using a subjective integration of hydraulic and geotechnical stability analyses include grade controls, bank protection, and small reservoirs. Aquatic habitat studies indicate that stone-protected stilling basins below grade-control weirs and habitats associated with drop pipes and stone spur dikes are assets to erosion damaged streams. This study does state some of the problems in analysis and rehabilitation of incised channels. For example, application of the idealized channel evolution model to specific watersheds is not straightforward. Each stream is a different entity with its own history and current state. Although the overall direction of channel evolution is known, predicting the long term response of specific reaches to stabilization and watershed land use change is uncertain. The goal of channel rehabilitation should be well-vegetated corridors along sinuous streams.

Simons, D.B., M.A. Stevens, and F.J. Watts, 1970. Flood Protection at Culvert Outlets. Wyoming State Highway Dept., U.S. Dept. of Transportation, Federal Highway Admin., Bureau of Public Roads, 218 pp.
This study is related to the flow conditions at culvert outfalls and to the hydraulics of rigid basins and outlet basins stabilized with rock riprap. The study is designed so that a hydraulic engineer can employ the information in the design of an energy dissipator of maximum effectiveness.

Simons, D.B., and G.L. Lewis, 1971. Flood Protection at Bridge Crossings. USGS, U.S. Department of Transportation, Federal Highway Administration, Bureau of Public Roads, Wyoming State Highway Department.
Techniques for the design of stable rock riprap protection in the vicinity of bridge crossings are presented. Hydraulic properties of the crossing are related to particle sizes for riprap protection of abutments and piers. This report is intended to be used as a design manual and an example of design protection.

Simons, D.B., and M.A. Stevens, 1971. Scour control in Rock Basins at Culvert Outlets, In*:* River Mechanics, Vol. 2, by H.W. Shen (Editor).
This study is directed toward defining and analysing scour control in rock basins at culvert outlets. Included are defining sections on the mechanism of local scour, flow conditions at culvert outfalls, dimensional analysis of local scour for

comparison of true versus experimental values, recommended field structures for control of scour, and design examples. This work is entirely devoted to analysis and recommendation of the amount of rock riprap necessary for control of scour around culvert outlets.

Smith, G.L., 1957. An Analysis of Scour Below Culvert Outlets. M.S. Thesis, Colorado State University, Fort Collins, Colorado.
"Scour is the condition caused by the movement of rock and earth particles, from channels and around hydraulic structures, by the kinetic energy of flowing water." Scour is of major concern in design of culverts. As the flow is concentrated through the culvert, the velocity of flow is increased, and the structure at the outfall is at risk of scour. This thesis concentrates its efforts on the investigation of the kinetic energy drop at circular culvert outlets, and its effects upon the bed material; this knowledge is then applied to the amount of necessary armorplating, with rock riprap.

Southard, R.E., 1992. Scour Around Bridge Piers On Streams in Arkansas. U.S. Geological Survey Water Resources Investigations Report 92-4126, 29 pp.
Scour is a major concern in the design of a new bridge or the evaluation of the structural stability of an existing bridge. This report describes the data obtained upon evaluation of select bridges in Arkansas. Previous studies have produced many equations for the evaluation of scour around a bridge; this study evaluates the application of these equations. This study also presents an equation based on the data collected here. The Froelich equation was found to be the best representative of this data. Prediction of scour using these equations tends to be a trick undertaking; one equation may predict almost no scour, while another might over-estimate the scour. Given these mixed results, the recent trend is to collect scour data during floods. Scour depths measured during floods are a result of unique site and flow conditions that are more complex and varied than flows produced in a laboratory.

Spence, J.D., and B.E. Larock, 1979.Interactive Computer-Aided Hydraulic Design: Culverts. Water Resources Bulletin 15(4):1153-1158.
Regular use of interactive computer programs in hydraulic design can materially increase the productivity of designers without sacrificing accuracy. This article considers the hydraulic design of culverts by interactive use of a computer program. This approach most profitably combines the speed and accuracy of the computer with the experience of the designer. "The fundamental problem in culvert design is to determine the most economical culvert size and shape required to pass a prescribed discharge through it without causing any unacceptable hydraulic behavior (e.g., too much backwater upstream, excessive scour downstream)."

Stevens, M.A., 1969. Scour in Riprap at Culvert Outlets. Ph.D. Dissertation, Colorado State University, Fort Collins, Colorado.
This dissertation presents the results of studies of circular culvert outlet basins formed of rock riprap. This analysis treats the relationship between the culvert flow and its interaction with the rock basin, and concludes with examples which illustrate the design of this type of outlet basin.

U.S. Army Corps of Engineers, Department of the Army, 1994. Engineering and Design: Channel Satbility Assessment for Flood Control Projects. U.S. Army Engineering Waterways Experiment Station, Vicksburg, Mississippi, EM 1110-2-1418, CECW-EH-D.
This manual provides help in determining potential channel instability and sedimentation effects in flood control projects. This report is intended to facilitate consideration of the type and severity of stability and sedimentation problems, the need for and scope of further hydraulic studies to address those problems, and design features to promote channel stability. The concept of channel stability implies that the plan, cross-section, and longitudinal profile of the channel are economicalyy maintainable within tolerable limits over the design life of the project.

U.S. Department of Interior, Bureau of Reclamation, 1965. Design of Small Dams.
This book presents instructions, standards, and procedures for use in the design of small dams. The book is intended to serve primarily as a guide to safe practices for those concerned with the design of small dams in public works programs in the U.S. The aims of this book are: 1) to provide engineers with information and data necessary for the proper design of small dams, 2) to provide specialized and highly technical knowledge concerning the design of small dams in a form that can be used readily by engineers who do not specialize in this field, and 3) to simplify design procedures for small earthfill dams. Of interest to this project is Chapter II, Flood Studies, that outlines many of the procedures necessary for the design of flood control dams. Also of interest is Chapter III, Selection of Type of Dam, and later chapters and sections concerning materials, earthfill dams, and rockfill dams.

Wolman, M.G. and L.M. Brush, Jr., 1961. Factors Controlling the Size and Shape of Stream Channels in Coarse, Non-Cohesive Sands. U.S. Geological Survey Professional Paper 282G:183-210.
The size and shape of equilibrium channels in uniform, non-cohesive sands [67 mm 2.0 mm in diameter] were studied experimentally in a laboratory flume 52 feet long in which discharge, slope, sediment load, and bed and bank material could be varied independently. For each run, a straight trapezoidal channel was molded in the sand and the flume set at a pre-determined slope. Introduction of the discharge was accompanied by widening and aggradation until a stable channel was established. By definition, a stable equilibrium existed when channel width, water surface slope, and rate of transport became constant.

Yarnell, D.L., 1934. Bridge Piers as Channel Obstructions, Technical Bulletin No. 442, U.S. Department of Agriculture. Washington D.C., Nov., 51 pp.

This investigation was done for the purpose of determining: 1) the effect of shape of pier upon the height of backwater caused by the pier, 2) the effect of length of pier upon the height of backwater, and 3) the effect of magnitude of contraction upon the height of backwater. The amount of obstruction that a pier causes depends upon: 1) the shape of the pier nose, 2) the shape of the pier tail, 3) the percentage of channel contraction caused by the pier, 5) the angle that the pier makes with the thread of the stream, and 6) the amount of discharge.

CHAPTER IV

CHANNEL MODIFICATION MITIGATIN BIBLIOGRAPHY

ECOLOGY

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CHANNEL MODIFICATION MITIGATION BIBLIOGRAPHY
ECOLOGY

INTRODUCTION

Stream channels are routinely modified or relocated during normal highway construction activities. The impacts of these activities upon riparian ecosystems depends on the extent of modification. Intuitively, the degree of impact is dependent upon several factors including stream width, rate of flow, frequency of flow, topography, soil texture, climate, as well as other factors. The degree of impacts is directly related to the magnitude of modification. Therefore the impacts can range from negligible--small streams with minor alterations, to significant--re-channelization and/or paved with concrete.

While highways and bridges are a required component of an industrialized nation, the growing concern for the environment has instigated an examination of construction procedures. Wetlands have become a battleground between environmental preservationists and developers. Contractors must now enlist environmentally-friendly construction methods to build bridges over various types of watercourses. The need for adequate environmental assessment, mitigation, and remediation during and after highway and bridge construction is necessary to gain public approval. Without the general public's consent, the project could become entangled in a legal conflict resulting in delays and possibly abandonment. Therefore bridge construction activities must be environmentally sound.

The objective of this report is to produce an annotated bibliography of the existing research pertaining to the ecological impacts of bridges and mitigation and/or remediation measures for those impacts. The biological components which are examined are amphibians, avifauna, fish, invertebrates, mammals, reptiles, and vegetation. The impacted chemical and physical characteristics of riverine habitats are also presented.

AMPHIBIANS

The lack of research pertaining to the impacts of stream alteration impacts on amphibians fosters an attitude of ignorance regarding these organisms. Since amphibians must reside within close proximity to water, stream alterations can significantly impact their populations. Vegetation destruction and wetland drainage appear to produce the most detrimental impacts. The impacts can be reduced by minimizing the severity of vegetation elimination and providing sheet-water areas for reproduction. Amphibians occupy a basic niche within riparian ecosystems which should be protected if possible.

AVIFAUNA

Avian species are dependant upon riparian habitat. The abundance and diversity of birds are related to the type and variety of stream bank vegetation and generally increases as plant succession advances. Therefore, the destruction of vegetation during stream alteration will negatively impact bird species richness, density, diversity, and composition. Mitigation of avian impacts would primarily involve the preservation of riparian vegetation while remediation would involve revegetation to aid the successional process by providing appropriate nesting and feeding sites. Since birds are aesthetically-pleasing to the public, avian conservation should be a primary concern.

FISH

Some of the specific ecological factors affecting fishes of running waters are oxygen content of the water, water temperature, current speed, fluctuations in discharge, dissolved salts, the substratum and turbidity, and various biotic factors. The most important abiotic factors are temperature, current speed, discharge fluctuation, and shelter availability. Stream alteration can modify these factors in such a way that fish movements, breeding patterns, and/or feeding habits are impacted.

A majority of the literature regarding stream alteration impacts and mitigation is concerned with fish species. The impacts are predominantly negative due to the loss of habitat through the removal of cover and loss of stream length. The impacts include reductions in species composition, diversity, density, and richness. Mitigating structures included jetties, random rock clusters, artificial riffles, artificial cover, double and single-wing rock deflectors, spring holes, wedge dams, modified wedge dams, K-dams, gabions, and culvert designs to facilitate fish passage (structural steel arch set in concrete footings, spoilers, offset baffles, and side baffles). The most successful structures were constructed of natural materials (rocks and logs). Other techniques to protect fish habitat are sediments traps, one-sided construction, low-impact debris removal, pool-riffle construction in bedrock, revegetation, and shade maintenance. Although the mitigation measures did not totally eliminate the fishery impacts, the magnitude and extent of the impacts were abated. Despite the varying recovery rates demonstrated in the reviewed studies (1 year to more than 60 years), it is believed that in wet climates the fishery resource requires less than 10 years to fully recover, but may never fully recover in drier climates.

INVERTEBRATES

Invertebrate communities of streams and rivers provide a sensitive index to changing conditions, more so than chemical and microbial information. Therefore, benthic invertebrates have been widely used as biological indicators of aquatic impacts related to stream pollution. Benthic invertebrate distribution is the result of many factors, for example substrate type, food quality and abundance, light, temperature, water movements and chemistry, oviposition habits, and predation, acting in combination. The most important factors which regulate the occurrence and distribution of streamdwelling invertebrates are current speed, temperature (latitudinal and seasonal effects), the substratum (including vegetation), and dissolved substances. Other important factors are liability to drought and to floods, food, competition between species, shade, and other environmental interactions. The construction of bridges over watercourses can possibly impact these factors.

Stream alteration can potentially alter invertebrate communities because of reduction in sinuosity and cover, and changes in current velocity and substrate composition. Despite the sensitivity of invertebrates to channel changes, most of the literature documented minimal impacts with rapid recovery (6 months to 1 year) of invertebrates. Successful mitigation measures reduced suspended sediments and sedimentation rates since substrate stability is probably the most important factor governing invertebrate populations.

MAMMALS

The species composition and abundance of mammals associated with streams is related to stream bank vegetation. An increase in the diversity of ground cover will stimulate an expansion of small mammal populations. Stream alteration impacts on mammals are correlated to the extent that stream banks are cleared. Small mammals are most affected by habitat changes following alteration, whereas large mammals with a larger home range are less affected. Mitigation and remediation measures which reduce the destruction of streamside vegetation provide the most benefit for mammals. Mammals are another aesthetically pleasing group of organisms which should be managed for their protection.

REPTILES

Little research exists pertaining to the impacts of stream alteration impacts on reptilian species. The most detrimental impacts for reptiles are vegetation destruction and wetland drainage. Mitigation of these impacts involves minimizing the extent of vegetation destruction and providing ponding areas for cover. Habitat conservation is critical for the survival of reptiles in riparian ecosystems.

VEGETATION

Vegetation (terrestrial and aquatic) must be considered as the most important biotic characteristic in riparian systems. The stability of the entire trophic structure depends upon the occurrence and abundance of plants as the primary producers. Factors controlling vegetation include temperature, light, current speed, the substratum, water alkalinity, mineral/nutrient supply, scour, water depth, grazing animals, and the liability to flooding or drought.

Stream alteration reverts succession of vegetation to an earlier seral stage. The succession of terrestrial vegetation follows the pattern of annual forbs, grasses, and then woody species. While the earlier seral stages might be preferable from the engineering standpoint, most wildlife species derive more benefits from the mature vegetational stages. Mitigating procedures include revegetation, sediment traps, one-sided construction, low-impact debris removal, pool-riffle construction in bedrock, shade maintenance, and fencing and vegetation markers. Benefits of vegetation management consist of erosion control, increased water quality through sediment reduction, bank stabilization, and protection of wildlife habitat.

CHEMICAL PROPERTIES

Water chemistry is an important aspect of riparian ecosystems. The short-term impacts of stream alteration appear to produce negligible impacts on water chemistry. The only significant chemical impacts mentioned in the literature involve the pollution of streams through contaminated highway runoff. These long-term impacts include such pollutants as litter, petroleum combustion products, rubber and metal from vehicles, dirt washed from vehicles, air-deposited substances, and ice-control chemicals. Control of these substances prior to contact with the surface water is important to reduce water chemistry alterations Polluted road and bridge runoff poses a potential threat to fragile riparian ecosystems.

PHYSICAL PROPERTIES

The principal impacts on the physical properties of stream channels are suspended solids, sedimentation, and substrate instability. When the solids are suspended in the water, plant growth may be impossible due to the reduction of light penetration. This will reduce the food supply of the herbivores and the detritivores which will have to rely on allochthanous detritus . Sedimentation of the inert solids smothers algal growths, kills rooted plants and mosses, and alters the structure of the substratum. For instance, the spaces between the stones may become clogged, thereby destroying the habitat of many animals. Substrate instability reduces the number of benthic invertebrates and aquatic vegetation. An integrated approach to vegetation mitigation can also aid erosion-control and the associated physical impacts.

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This report details the impacts of stream alteration in the grasslands of Oklahoma. "Conclusions and recommendations are given on the effects of stream alteration to riparian vegetation and associated bird, mammal, amphibian, and reptile populations."

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This report compiles information regarding stream channelization studies in eight states. "Effects on macroinvertebrate abundance and diversity, fish numbers and biomass, mammal and bird populations, reptile and amphibian abundance and diversity are all discussed. Recommendations for assessing impact and developing alternative measures in stream channelization are also discussed."

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This report evaluates the impacts of channelization on benthos and wildlife of a Vermont river. After 8 months there was no significant difference in the benthic organisms of channelized and unchannelized areas. The majority of songbirds and small mammals were captured in the unchannelized areas, which also had the greatest species diversity. "No gross differences were observed between channelized and control (non-channelized) sites for the furbearers and amphibians. The most drastic impact on wildlife occurred at channelized sites where streamside vegetation was the most extensively destroyed."

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This paper evaluates the plant and animal species composition and abundance in regards to plant successional stages from grassland to mature woods adjacent to recently dredged (6 years), old dredged (50 years), and natural streams in Wisconsin. "Bird and mammal species diversity and bird abundance increased as plant succession advanced, until a mature wooded stage was reached. Abundance of small mammals was related to the amount of ground cover and the diversity of habitats along the stream banks. Reptile and amphibian species diversity was greatest along natural and old dredged streams having partially submerged branches and low-lying, moist areas...Waterfowl use, bird nesting, and reptile and amphibian abundance also were greatest on the undrained area"

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This report evaluates the impacts of channelization on benthos and wildlife of a Vermont river. After 8 months there was no significant difference in the benthic organisms of channelized and unchannelized areas. The majority of songbirds and small mammals were captured in the unchannelized areas, which also had the greatest species diversity. "No gross differences were observed between channelized and control (non-channelized) sites for the furbearers and amphibians. The most drastic impact on wildlife occurred at channelized sites where streamside vegetation was the most extensively destroyed."

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influence of stream channelization upon wildlife and their habitats." This is a good reference regarding successional processes along channelized rivers.

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This paper evaluates the plant and animal species composition and abundance in regards to plant successional stages from grassland to mature woods adjacent to recently dredged (6 years), old dredged (50 years), and natural streams in Wisconsin. "Bird and mammal species diversity and bird abundance increased as plant succession advanced, until a mature wooded stage was reached. Abundance of small mammals was related to the amount of ground cover and the diversity of habitats along the stream banks. Reptile and amphibian species diversity was greatest along natural and old dredged streams having partially submerged branches and low-lying, moist areas...Waterfowl use, bird nesting, and reptile and amphibian abundance also were greatest on the undrained area"

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Benson, N. G. and A. S. Weithman. 1980. ***Seven U. S. Fish and Wildlife Stream Channelization Studies*****, National Water Resources Analysis Group, Eastern Energy Land Use Team, Office of Biological Services, Fish and Wildlife Service, 54 pp.**
This report compiles information regarding stream channelization studies in eight states. "Effects on macroinvertebrate abundance and diversity, fish numbers and biomass, mammal and bird populations, reptile and amphibian abundance and diversity are all discussed. Recommendations for assessing impact and developing alternative measures in stream channelization are also discussed."

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This paper evaluates the effects of channelization on the growth and feeding of fish in an Ohio river. The overall effects of channelization and mitigation were minimal. The changes in the "macrobenthic community translated into differences in the composition and density of the sport fish community at each site, rather than into feeding and growth differences." Channelization has more of an impact on fish community dynamics than on feeding and growth.

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"This report summarizes the results given in 5 other subproject reports" regarding stream alteration in Iowa. The "differences in populations of fish and fish-food organisms in channelized and unchannelized streams, effects of stream alterations for highway bridge construction, and the value of stream-bank stabilization structures to fish habitat" are the topics covered.

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This paper evaluates the impacts of stream alteration on the trout fishery in the mountains of Colorado. Over the four year period the survey data failed to show any significant changes in the fishery. The channel was lined with large rocks and boulders and several were left in the stream.

Burns, J. W. 1972. "Some effects of logging and associated road construction on Northern California streams." *Transactions of the American Fisheries Society*, 101, 1-17.
Logging and road construction impacts of California streams are presented. "Extensive use of bulldozers in stream channels during debris removal caused excessive streambed sedimentation in narrow streams." Thinning the riparian canopy of streams can increase the water temperature. In cold, shaded streams this can lead to an increase the production of algae, bacteria, and insects upon which fish feed. However, too much shade removal can also be detrimental to aquatic organisms.

Burnside, K. R. 1967. *The Effects of Channelization on Fish Populations in Boeuf River in Northeast Louisiana*, M. S. Thesis, Northeast Louisiana State College, Monroe, 27 pp.

This paper compares the fish populations in dredged and undredged sections of the Boeuf River in Louisiana. The altered section showed a significant decline in the abundance of some species.

Cederholm, C. J. 1972. *The Short-Term Physical and Biological Effects of Stream Channelization at Big Beef Creek, Kitsap County, Washington*, M. S. Thesis, University of Washington, Seattle Washington, 80 pp.
This paper evaluates the effects of channelization in a Washington stream. The initial negative impacts upon the fishery are discussed.

Cederholm, C. J. and K. V. Koski. 1977. *Effects of Stream Channelization on the Salmonid Habitat and Population of Lower Big Beef Creek, Kitsap County, Washington 1969-73*, University of Washington, Seattle, Washington, 31 pp.
This paper investigates the physical and biological effects of stream channelization in a Washington creek. The stream environment has not fully recovered after five years. "Channelization was found to be incompatible with good anadromous fish production."

Chapman, D. W. and E. Knudsen. 1980. "Channelization and livestock impacts on salmonid habitat and biomass in Western Washington." *Transactions of the American Fisheries Society*, 109, 357-363.
"Channelization significantly reduced overhead cover, sinuosity, wetted area, and woody bank cover while increasing bank grasses. Total habitat area declined in altered areas." These alterations negatively affected the larger fish species.

Cline, L. D., R. A. Short, J. V. Ward, C. A. Carlson, and H. L. Gary. 1983. "Effects of highway construction on water quality and biota in an adjacent Colorado mountain stream." Research Note RM-429, 10 pp.
The impacts of highway construction upon a Colorado stream are detailed. "Highway construction increased total suspended solids and channel sedimentation, while other water quality variables (total dissolved solids, organic fraction of dissolved solids, organic fraction of suspended solids, dissolved oxygen, free and bound carbon dioxide, pH, temperature, and discharge) were unaffected in and adjacent, high elevation stream. Epilithon standing crop and macroinvertebrate density decreased and compositional changes were noted. Effects were more pronounced in depositional areas. No change in fish condition was detected."

Congdon, J. C. 1971. "Fish populations of channelized and unchannelized sections of the Chariton River, Missouri." *Stream Channelization: A Symposium*, North Central Division American Fisheries Society Special Publication No. 2, Eds. E. Schneberger and J. L .Funk, 52-62.
The effects of channelization on a Missouri fishery are discussed. Total standing crop was reduced by 87% while the standing crop of catchable-size fish was reduced by 89%. Twenty-one species occurred in the unchannelized section compared to 13 in the channelized section.

Cooper, C. O. and T. A. Wesche. 1976. "Stream channel modification to enhance trout habitat under low flow conditions." *Water Resources Series No. 58*, Water Resources Research Institute, University of Wyoming, Laramie, 107 pp.
This paper analyzes the effects of modification of Douglas Creek, Wyoming, to constrict and consolidate low flows and thereby increase trout habitat.

Dale, E. E., Jr. 1974. *Environmental Evaluation Report on Various Completed Channel Improvement Projects in Eastern Arkansas*, Final Report to the U. S. Army Corps of Engineers, Little Rock District, Little Rock, Arkansas, 44 pp.
This report evaluates the "beneficial and adverse effects that certain channel improvement projects have had on the natural or man-made environments of selected areas in Eastern Arkansas." This paper presents a time-table of seven vegetation successional stages. This describes the dominant vegetation occurring at different times (0 to 50 years) along the streams. Fish and wildlife impacts are also discussed regarding individual species.

Dane, B. G. 1978. "A review and resolution of fish passage problems at culvert sites in British Columbia." *Fisheries and Marine Service Technical Report No. 810*, Department of Fisheries and Environment, Canada, 126 pp.
This report analyzes the problems which culverts pose to fish in British Columbia. Design recommendations of culverts which should permit the free passage of fish under most circumstance are also presented.

Dryden, R. L. and C. S. Jessop. 1974. "Impact analysis of the Dempster Highway culvert on the physical environment and fish resources of Frog Creek." *Technical Report Series No. CEN/T-74-5*, Environment Canada, Fisheries and Marine Service, Resource Management Branch, 59 pp.
This report discusses the impacts of improper culvert design on the hydrology and fish biology of a Canadian stream. The most severe impact was the delay in fish migration due to increased water velocities.

Edwards, C. J. 1977. *The Effects of Channelization and Mitigation on the Fish Community and Population Structure in the Olentangy River, Ohio*, Ph.D. Dissertation, Ohio State University, Columbus, Ohio, 161 pp.
This paper provides detailed information of the fish community in an Ohio river following channelization. The overall impact on community structure from channelization and mitigation was negative.

Edwards, C. J., B. L. Griswold, and G. C. White. 1975. "An evaluation of stream modification in the Olentangy River, Ohio." *Symposium on Stream Channel Modification Proceedings*, August 15-17, Harrisonburg, Virginia, 34-49.
This article compares fish species composition and relative abundance between a natural section of the river, a section modified in 1970 by the construction of artificial riffle-pool structures, and a section modified conventionally in 1950 by shortening, widening, and deepening the channel.

Elser, A. A. 1967. *Fish Populations of a Trout Stream in Relation to Major Habitat Zones and Channel Alterations*, M. S. Thesis, Montana State University, Bozeman, Montana, 26 pp.
This paper describes the fishery impacts of channel alteration in a Montana stream. Rock deflectors provided "physical characteristics comparable to unaltered sections, except vegetative cover."

Elser, A. A. 1968. "Fish populations of a trout stream in relation to major habitat zones and channel alterations." *Transactions of the American Fisheries Society*, 97, 389-397.
The impacts of stream alterations on fish populations in a Montana stream were discussed in this article. Trout and other fish species were more numerous in the unaltered sections. "Channel alterations resulted in a total loss of 4,700 trout with a total weight of 2,200 pounds"

Etnier, D. A. 1972. "The effect of annual rechanneling on a stream fish population." *Transactions of the American Fisheries Society*, 101(2), 372-375.
The impacts of channeling a Tennessee stream for flood control purposes is discussed. The fish fauna was significantly changed and the invertebrate diversity decreased.

Forshage, A. and N. E. Carter. 1973. "Effects of gravel dredging on the Brazos River." *Proceedings of the 24 th Annual Conference of Southeastern Association of Game and Fish Commissioners*, 24, 695-708.
This paper discusses the physicochemical and biological changes of the Brazos River following a gravel dredging operation and the effects on the river fauna. The study concluded "that gravel operations can influence stream substrate type, reduce the abundance of bottom-dwelling invertebrates, and change fish populations to favor less desirable species."

Funk, J. L. and J. W. Robinson. 1974. "Changes in the channel of the lower Missouri River and effects on fish and wildlife." *Aquatic Series No. 11*, Missouri Department of Conservation, 52 pp.
This report is a historical presentation of the channel changes in the Missouri River. The detrimental effects upon fish and wildlife due to the changes are described.

Gebhards, S.V. 1973. "Effects of channelization on fish." *Trout.* 14(1), 22 and 24.
This article briefly describes the impacts of channelization on streams (chemical, physical, and biological) and uses illustrations from Idaho.

Gersmehl, J. and T. Meyers. No date. *Effects of Stream Channelization on Trout Populations of the White River, Vermont*, U. S. Fish and Wildlife Service, Fishery Assistance, Mont Pelier, Vermont, 39 pp.
This report evaluated the impacts of channelization on trout in a Vermont river.

Stream alteration severely affected trout populations. "The average reduction in density for all trout species at all sites during 1974-1977 was approximately 50%." Recommendations are also made regarding alterations of trout streams.

Golden, M. F. and C. E. Twilley. 1976. "Fisheries investigation of a channelized stream, Big Muddy Creek Watershed, Kentucky." ***Transactions of the Kentucky Academy of Science*****, 37, 85-90.**
This paper describes the impacts of channelization on a Kentucky fishery. "Biomass and number of species were reduced significantly in channelized areas as compared to unchannelized areas. This indicates full recovery has still not occurred after 33 years..." The reductions in fish diversity and biomass is attributed to habitat alteration since the water quality is generally within acceptable limits.

Griswold, B. L., C. Edwards, L. Woods, and E. Weber. 1978. ***Some Effects of Stream Channelization on Fish Populations, Macroinvertebrates, and Fishing in Ohio and Indiana*****, U. S. Fish and Wildlife Service, Biological Services Program, FWS/OBS-77/46, 64 pp.**
"The effects of stream channelization on warm water fish and macroinvertebrate population were studied in five streams by comparing the biota in natural areas to that in nearby channelized areas...In general, channelization adversely affected macrobenthos diversity, abundance, and/or biomass, and it caused a shift in species composition from riffle species to less desirable standing water burrowing forms...The biota of the mitigated area...approximated that of the natural area."

Hamilton, J. D. 1961. "The effect of sand-pit washings on a stream fauna." International Association of Theoretical and Applied Limnology, 14, 435-439.
This paper reports that the impacts of sediments upon the bottom fauna and fish are minimal and recolonization of affected areas occurred six months after the sediments were reduced.

Hansen, D. R. 1971a. ***Effects of Stream Channelization on Fishes and Bottom Fauna in the Little Sioux River, Iowa*****, M.S. Thesis, Iowa State Univ, Ames,** ***Iowa*****, 119 pp.**
This paper evaluates the differences in physical factors, bottom fauna, and fish populations in channelized and unchannelized portions of an Iowa river. The channelized section produced greater daily water temperature fluctuations and higher turbidities. "Results of the investigation revealed certain differences in bottom fauna and fish fauna between the two sections of the river." Channel catfish proved to be an excellent indicator of the channelized conditions. "Conditions in the channelized section were not as favorable for stable populations of larger game fishes."

Hansen, D. R. 1971b. "Stream channelization effects on fishes and bottom fauna in the Little Sioux River, Iowa." ***Stream Channelization: A Symposium*****, North Central Division American Fisheries Society Special Publication No. 2, Eds. E. Schneberger and J. L. Funk, 29-51.**
This paper describes the differences in certain physical factors, bottom fauna, and

fish populations in channelized and unchannelized portions of an Iowa river. Water temperatures, temperature fluctuations, and turbidities were higher in the channelized section. Composition of bottom fauna was similar in both sections. Numbers of fish species was greater in the unchannelized section. Lack of suitable habitat was the most obvious cause for the fish differences.

Hansen, D. R. and R. J. Muncy. 1971. "Effects of stream channelization on fishes and bottom fauna in the Little Sioux River, Iowa." Completion Report of Project No. A-035-IA, Iowa State Water Resources Research Institute, 118 pp.
This paper reports the findings of a study which evaluated the differences in certain physical factors, bottom fauna, and fish populations in channelized and unchannelized portions of the Little Sioux River, Iowa, occurring 1969-71.

Hathaway, C. B., Jr. 1978. *Stream Channel Modification in Hawaii, Part C: Tolerance of Native Stream Species to Observed Levels of Environmental Variability*. FWS/OBS-78/18. USFWS National Stream Alteration Team, Columbia, Missouri. 59 pp.
This booklet describes the increases in physicochemical variations (conductivity, pH, and dissolved oxygen) correlated to channel modification of Hawaiian streams. These variations were determined to reduce the abundance of several endemic gobiid fishes in the altered streams.

Headrick, M. R. 1976a. *Effects of Stream Channelization on Fish Populations in the Buena Vista Marsh, Portage County, Wisconsin*, M. S. Thesis, University of Wisconsin, Stevens Point Wisconsin, 65 pp.
This paper compares the fish populations in unchannelized, 6-8 year old channelized, and 52-62 year old channelized streams in Wisconsin. "Approximate equality of these parameters (brook trout density, production, and angler success) in the upstream old ditch and natural stream indicated that recovery of natural channel morphology and trout carrying capacity was nearly complete after 60 years...The natural stream had the greatest number of fish species" while the new ditch had the fewest.

Headrick, M. R. 1976b. *Effects of Stream Channelization on Fish Populations in the Buena Vista Marsh, Portage County, Wisconsin*, U. S. Fish and Wildlife Service, Office of Biological Services, FWS/OBS-76/24, 38 pp.
This paper compares fish populations from 6-8 year old and 52-62 year old ditches with populations of natural streams. Channelization reduced year-round instream cover, decreased substrate stability, and increased silt accumulation and stream temperatures. The impacts regarding these changes are discussed for several fish species. "Recovery was more rapid in ditches where spoil was spread on adjacent fields and bank vegetation left in place than in ditches where loose spoil was left on the banks." Recommendations for trout management of dredged streams are given.

Hickman, G. D. 1975. "Value of instream cover to the fish populations of Middle Fabius River, Missouri." *Aquatic Series, No. 14*, Missouri Department of Conservation, Jefferson City, Missouri, 7 pp.

This report compares the fish populations in areas of a Missouri river with and without an abundance of instream cover. The total fish population and catchable-size fish population of stations without instream cover were 25% and 51% lower, respectively, than stations with instream cover. "No significant differences in length-weight relationships of six species were detected..."

Holz, D. D. 1969. *The Ecology of the Unchannelized and Channelized Missouri River, Nebraska, with Emphasis on the life History of the Flathead Catfish*, M. A. Thesis, University of Missouri, Columbia, Missouri, 118 pp.
This study researched the ecological differences of channelized and unchannelized section of the Missouri River in Nebraska. "Growth rate of the flathead catfish was faster in the channelized river than in the unchannelized river...a collapse in population structure had taken place in the channelized river but not in the unchannelized river...The standing crop of aufwuchs was lowest in the channelized river...In the channelized Missouri the rate of flow was greater then in the unchannelized river...Turbidity was greater in the channelized section. The chemical properties were similar."

Hortle, K. G. and P. S. Lake. 1983. "Fish of channelized and unchannelized sections of the Bunyip River, Victoria." *Australian Journal of Marine and Freshwater Research*, 34, 441-450.
This paper presents the results of a study in Australia. The unchannelized sections had significantly higher species richness, biomass, numerical density, and standing crop. The absence of suitable habitat accounted for the differences, however "a small weir at one of the channelized sites ameliorated partly the effects of channelization."

Huckabee, J. W., C. P. Goodyear, and R. D. Jones. 1975. "Acid rock in the Great Smokies: unanticipated impact on aquatic biota of road construction in regions of sulfide mineralization." *Transactions of the American Fisheries Society*, 104(4), 677-684.
Roadbed fill material containing iron sulfide minerals was detrimental to the fish and salamander populations in a stream in Tennessee. The downstream water had an acidic pH (4.5 to 5.9) while the upstream water pH was neutral (6.5 to 7.0).

Huggins, D. G. and R. E. Moss. 1974. "Fish population structure in altered and unaltered areas of a small Kansas stream." *Transactions of the Kansas Academy of Science*, 77(1), 18-30.
This paper presents the results of a study "designed to determine summer fish populations, species succession, species diversities, and standing crop estimated in a small, slow moving, warm water stream" in Kansas "that supported a population of cyprinids and other 'non-sport fish' species." Channelization was determined to cause lower biomass and numbers of fish, and lower diversity index values.

Irizarry, R. A. 1969. *The Effects of Stream Alteration in Idaho*, Idaho Fish and Game Department, Federal Aid in Fish and Wildlife Restoration, Job Completion Report Project F 55-R-2, 26 pp.
This is a three-part report which examines 1) "the inventory of amount, type, and location of channel alterations; 2) physical changes in stream habitat following channel alterations; and 3) biological changes in stream habitat following channel alterations" in Idaho. This report focuses on fisheries impacts and found that "average fish production, in poundage was 8 times greater in undisturbed stream sections; while in numbers of game fish, the natural area out-produced the altered areas 6 to 1."

Kendle, E. R. 1970. "The effects of channelization in the Missouri River on fish and fish-food organisms." *Nebraska Game and Parks Commission*, 5 pp.
This paper attempts to identify the fish which will most likely be seriously affected by a channelization project on the Missouri River. Habitat loss is considered to be the major source of impact.

King, D. L. and R. C. Bell. 1964. "Influence of highway construction on a stream." *Research Report 19, Michigan State University, Agricultural Experiment Station, East Lansing*, 4 pp.
This is an evaluation of destruction of natural stream environment by channel realignment. Effects on the aufwuchs (basic producers), invertebrates, fish, and stream energetics are discussed.

King, L. R. and K. D. Carlander. 1976. *A Study of the Effects of Stream Channelization and Bank Stabilization on Warmwater Sport Fish in Iowa: Subproject No. 3. Some Effects of Short-Reach Channelization on Fishes and Fish Food Organism in Central Iowa Warm Water Streams*, U. S. Fish and Wildlife Service, Biological Services Program, FWS/OBS-76/13, 217 pp.
This reports the results of a study conducted "to determine whether fish and fish food organisms were affected by short-reach channelization associated with bridge replacement in the last 15 years" in Iowa. This study analyses different successional stages of channelized streams--2 and 10 to 15 years after channelization--and unchannelized streams. "The most evident impact of short-reach channelization is the removal of cover in the altered area and the loss of stream length."

Kratt, L. F. 1981. "Evidence of Arctic grayling (*Thymallus arcticus*) spawning in a highway culvert." *The Canadian Field-Naturalist*, 95, 358.
This article surmises that in some circumstances road construction materials may enhance aquatic habitats. "The construction and maintenance of the Alaska Highway have resulted in gravel deposits at many stream crossing locations. These deposits provide suitable spawning areas in creeks which would normally not be utilized by Arctic Grayling for reproductive purposes."

Kszos, L. A., J. D. Winter, and T. A. Storch. 1990. "Toxicity of Chautauqua Lake Bridge runoff to young-of-the-year sunfish (*Lepomis macrochirus*)." *Bulletin of Environmental Contamination and Toxicology*, 45, 923-930.
"This study was conducted to evaluate the potential toxicity of runoff from the Chautauqua Lake bridge to young-of-the-year bluegill sunfish." Despite the high toxicity of the runoff, it was not toxic to fish in the lake because of the magnitude of dilution. Similar runoff in a much smaller body of water would probably cause significant harm to freshwater organisms.

Langemeier, R. M. 1965. *Effects of Channelization on the Limnology of the Missouri River, Nebraska, with Emphasis on Food Habits and Growth of the Flathead Catfish*, M. A. Thesis, University of Missouri, Columbia, MO, 156 pp.
This paper evaluates the limnological differences in channelized and unchannelized portions of the Missouri River. The chemical properties were similar. The growth rates of the flathead catfish was slower in the unchannelized section. Invertebrate drift was a good index for catfish growth. "The difference in the abundance of aufwuchs and the difference in the degree of aggregation of these organisms is assumed to be the reason for the difference in size of young-of-the-year flathead catfish between the two stations.

Larimore, R. W. and P. W. Smith. 1963. "The fishes of Champaign County, Illinois, as affected by sixty years of stream changes." Illinois Natural History Survey Bulletin, Vol. 28, 299-382.
This paper details the changes in the fish population in part of Illinois. The changes apparent throughout the study included agricultural development, population increase, natural and human stream channel modifications, and new developments in land use practices. The adaptability of the fish to these changes is evaluated.

Larson, L. L. and S. L. Larson. 1996. "Riparian shade and stream temperature: a perspective." *Rangelands*, 18(4), 149-152.
This article discusses riparian shade as a means to prevent heating of streams. The changes in water temperature can alter the species composition of streams. "Streamside vegetation can improve bank stability, increase habitat for some species of wildlife, and serve as a component in the system as a whole but shade does not control stream temperature."

Lewis, S. L. 1969. "Physical factors influencing fish populations in pools of a trout stream." *Transactions of the American Fisheries Society*, 98(1), 14-19.
Fish populations and physical parameters were studied in a Montana stream. The most important factors for brown and rainbow trout were cover and current velocity, respectively. "Deep-slow pools with extensive cover had the most stable trout populations."

Little, A. D, Inc. 1973. *Report on Channel Modifications, Volume I*, Prepared for the Council on Environmental Quality, U. S. Government Printing Office, Washington D. C., 394 pp.

This report details the "effects of channel modification and clearing of flood plain hardwoods on fish and wildlife resources, habitats, diversity of species, and productivity."

Lund, J. A. 1976. *Evaluation of Stream Channelization and Mitigation on the Fishery Resource on the St. Regis River, Montana*, U. S. Fish and Wildlife Service, Biological Services Program, FWS/OBS-76/06, 49 pp.
Stream channelization effects on stream morphology and gamefish populations due to highway and railroad construction are presented. Mitigating structures (jetties and random rock clusters) were effective in providing fish habitat. Fish populations stabilized in about one year in new channels.

Marzolf, G. R. 1978. *The Potential Effects of Clearing and Snagging on Stream Ecosystems*, U. S. Fish and Wildlife Service, Biological Services Program, FWS/OBS-78/14, 31 pp.
This report "identifies some potential ecological impacts of clearing and snagging, but does not yield quantitative predictions of the impacts." The effects of clearing and snagging on primary producers, decomposition, organic matter processing, macroinvertebrates, and fish are discussed.

McClellan, T. J. 1970. *Fish Passage Through Highway Culverts: A Field Evaluation*, U. S. Department of Transportation, Federal Highway Administration, 150 pp.
This report evaluates the effectiveness of culvert design in regards to fish passage. The designs and types of structures to aid fish passage are provided and prove to be successful in aiding fish passage. Tabulated data concerning the different culvert types are also provided.

McClellan, T. J. 1973. *Study and Evaluation of Stream Channel Changes and Their Effects on Fish Habitat - A Case Study*, U. S. Department of Transportation, Federal Highway Administration, Case Study Report, 19 pp.
This is a case study of the altered Wildcat Creek in Oregon, to gather information regarding the ecological impacts of stream channel changes and the potential for recovery capability. An outline for a study proposal is provided.

McClellan, T. J. 1974. *Ecological Recovery of Realigned Stream Channels*, U. S. Department of Transportation, Federal Highway Administration, Field Investigation Report, 78 pp.
This report determines the long-term effects of man-made channel changes on fish in Oregon. The natural recovery rate is assessed and methods are evaluated to minimize damage for future channel change projects. Recommendations are given to help minimize the impacts and facilitate the recovery from channel changes. The bulk of the report is Appendix A - Site Review Notes and Photographs of 18 different changed channel projects.

Menzel, B. W. and H. L. Fierstine. 1976. *A Study of the Effects of Stream Channelization and Bank Stabilization on Warmwater Sport Fish in Iowa: Subproject No. 5. Effects of Long-Reach Channelization on Distribution and Abundance of Fishes*, U. S. Fish and Wildlife Service, Biological Services Program, FWS/OBS-76/15, 108 pp.
This report details the "relationships between habitat characteristics and the distribution and abundance of fishes" in natural and channelized Iowa streams. "Species diversity appeared to be primarily a function of stream gradient...These data suggest that there is greater fish movement throughout straightened reaches..Condition factor and length-weight relationships of channel catfish carp, and river carpsucker showed little difference between collection from channelized and unchannelized areas."

Metsker, H. E. 1970. "Fish versus culverts: some considerations for resource managers." *Engineering Technical Report, ETR-7700-5*, Forest Service, U. S. Department of Agriculture, 19 pp.
This paper presents problems that culverts impose upon fish. Design and reconstruction recommendations are presented to mitigate the impacts.

Miller, R. R. 1961. "Man and the changing fish fauna of the American Southwest." *Michigan Academy of Science, Arts, and Letters*, 46, 365-404.
This paper details the changes which have occurred in the fish fauna of the Southwest. Environmental modifications are described and linked to modern man.

Montalbano, F., III, K. J. Foote, M. W. Olinde, and L. S. Perrin. 1979. "The Kissimmee River channelization: a preliminary evaluation of fish and wildlife mitigation measures." *The Mitigation Symposium: A National Workshop on Mitigating Loss of Fish and Wildlife Habitats*, July 16-20, Colorado State University, Fort Collins, Colorado, Rocky Mountain Forest and Range Experiment Station General Technical Report RM-65, 508-515.
This paper determined that despite mitigation measures implemented during the channelization of a Florida river the fish and wildlife were negatively impacted.

Moyle, P. B. 1976. "Some effects of channelization on the fishes and invertebrates of Rush Creek, Modoc County, California." *California Fish and Game*, 62(3), 179-186.
This paper examines the differences in fish and invertebrate populations due to channelization in a California stream. "Overall, total fish biomass in the channelized sections was less than one-third of that in the unchannelized sections. The biomass of invertebrates in the channelized sections was found to be less than one-third of that in the unchannelized sections."

Murphy, M. L., C. P. Hawkins, and N. H. Anderson. 1981. "Effects of canopy modification and accumulated sediment pollution on stream communities associated with clear-cut logging in the Western Cascade Range of Oregon." *Transactions of the American Fisheries Society*, 110, 469-478.

The impacts of canopy modification and increased sediments on a stream in Oregon are presented. "Streams traversing open clear-cuts had greater rates of microbial respiration, and greater densities or biomasses of aufwuchs, benthos, drift, salamanders, and trout than did the shaded, forested sites regardless of sediment composition. It is concluded that for these small Cascade Range streams, changes in trophic status and increased primary productivity resulting from shade removal may mask or override effects of sedimentation."

Osborn, J. F. and J. W. Anderson. 1986. "Stream improvement and fish response: a bio-engineering assessment." ***Water Resources Bulletin*****, 22(3), 381-388.**
This article describes the positive and negative impacts of stream modifications upon fish. Stream improvements for restoring or enhancing fish habitats are discussed.

Perry, E. W. 1974. "The effect of stream improvement structures on the sport fishery in a channelized section of the Olentangy River." M. S. Thesis, Ohio State University, 130 pp.
This paper evaluates the effectiveness of artificial stream improvement structures installed after channelization due to highway construction in a river near Columbus, Ohio. The artificial riffles did prevent an ecological disaster in the channelized section of the river but the catch rates are still not comparable to the unchannelized section.

Peters, J. C. 1972. "Effects of sediment control on fish populations." ***Colorado Fisheries Research Review*****, Colorado Department of Game, Fish, and Parks, 7, 50-51.**
This article briefly describes the variable effects of certain fish species to a reduction in sediment discharge in a Colorado River.

Peters, J. C. and W. Alvord. 1963. "Man-made channel alterations in thirteen Montana streams and rivers." ***Proceedings of the Twenty-Ninth North American Wildlife Conference*****, 93-101.**
This presentation reports the impacts of channel modifications on fish in Montana. Carrying capacity and standing crops of game fish were significantly reduced in altered streams.

Pilli, A., D. O. Carle, E. Kline, Q. Pickering, and J. Lazorchak. 1988. "Effects of pollution on freshwater organisms." ***Journal of the Water Pollution Control Federation*****, 60(6), 994-1065.**
This is a very extensive literature review of the impacts of pollutants (toxic chemicals, effluents, leachates, oils, and pH effects) on freshwater organisms (fish, invertebrates, and algae.)

Porter, T. R., D. M. Rosenberg, and D. K. McGowan. 1974. *Winter Studies of the Effects of a Highway Crossing on the Fish and Benthos of the Martin River, N. W. T.*, Environment Canada, Fisheries and Marine Service Technical Report Series No. CEN/T-74-3, 50 pp.
This report details the impacts of a highway crossing on the fish and benthos of a Canadian river. "There was no clear indication that the Martin River highway crossing and related winter activities had any discernible effects on the fish and benthic fauna through the winter of 1972-1973."

Reed, J. R. 1977. "Stream community response to road construction sediments." *Virginia Water Resources Research Center Bulletin 97*, 61 pp.
"This publication summarizes a two-year study in the effectiveness of erosion-control measures, the effect of silt on macrobenthic and fish populations, and the ability of these populations to recover from stream degradation."

Rees, W. H. 1959. "Effects of stream dredging on young silver salmon (*Oncorhynchus kisutch*) and bottom fauna." *Fisheries Research Papers*, Washington Department of Fisheries, Seattle, Washington, 2(2), 53-65.
This paper evaluates the biological changes in a Washington stream due to rechanneling operations. The bottom fauna "recovered completely" within 11 months after dredging. Silver salmon "population estimates made a year later compared favorably in test and control areas with estimates made" prior to dredging.

Saunders, J. W and M. W. Smith. 1965. "Changes in a stream population of trout associated with increased silt." *Journal of the Fisheries Research Board of Canada*, 22(2), 395-404.
This paper presents the impacts of silt and the adaptability of brook trout in a stream on Prince Edward Island. Low standing crop and reduction in spawning were the primary impacts.

Scarnecchia, D. L. 1988. "The importance of streamlining in influencing fish community structure in channelized and unchannelized reaches of a prairie stream." *Regulated Rivers: Research and Management*, 2, 155-166.
This paper compared channelized and unchannelized sections of an Iowa stream to "determine how differences in microhabitats affected fish species abundance and diversity and the incidence of streamlined species...Channelized sections had significantly more fish per unit area ($P < 0.05$) but significantly less biomass ($P < 0.05$)...Species diversity was lower in channelized sections, but differences were non statistically significant ($P = 0.06$). Family diversity was significantly lower in channelized sections ($P < 0.05$)."

Schaplow, B. M. 1976. "The effects of channelization and mitigation on the morphology and trout populations of the St. Regis River Montana." M. S. Thesis, Montana State University, Bozeman, Montana, 46 pp.
This study measured trout populations and stream morphology changes to determine the impacts of highway and railroad construction activities along the St. Regis River, Montana.

Schoof, R. 1980. "Environmental impact of channel modification." *Water Resources Bulletin*, 16(4), 697-701.
This is a literature review which tries "to identify and quantify the effects of channelization and to examine the feasibility and acceptability of alternative methods of flood control. Channelization reduces the size, number, and species diversity of fish in streams. In a wet climate, the fishery requires less than 10 years to fully recover. However, in drier climates, the fishery may never fully recover."

***Sport Fishing Institute Bulletin*, 1962. "Road-building and fishing." No. 124, 1-2.**
This brief paper describes the detrimental effects of road construction activities (channelization, dredging, poorly designed culverts, and suspended sediments) on fisheries.

***Sport Fishing Institute Bulletin*, 1971. "Effects of channelization." No. 230, 3-4.**
This is a brief article listing the conclusions of the Tarplee, Louder, and Weber (1971) paper.

Stroud, R. 1971. "Stream destruction by channelization." *Sport Fishing Institute Bulletin*, No. 226, 1-3.
This brief article describes the detrimental effects which channelization has upon fisheries.

Swedberg, S. E. and Nevala. 1965. "Evaluation of fish habitat destruction in Little prickly Pear Creek due to construction of Interstate Highway 15." Montana Fish and Game Department, *Job Completion Report, F-5-R-14*, 11 pp.
This paper presents the data for temperature, water quality and quantity, bottom fauna, and fish for the creek in graphs and tables. This is a preliminary investigation that does not provide any conclusions and the only recommendation is to continue the study.

Tarplee, W. H., Jr., D. E. Louder, and A. J. Weber. 1971. *Evaluation of the Effects of Channelization on Fish Populations in North Carolina's Coastal Plain Streams*, North Carolina Wildlife Resources Commission Report, 22 pp.
This paper reports the damage, if any, to fish populations due to channelization and the rate of recovery if damage was significant in North Carolina streams. Some of the conclusions of the study include "the greatest single factor affecting a fish population appears to be the amount of stream cover, channelization appears to adversely affect game fish more than nongame fish, and fish populations, as represented by species diversity, in a channelized stream may recover in about 15 years if there are no further alterations."

Trautman, M. B. 1939. "The effects of man-made modifications on the fish fauna in Lost and Gordon Creeks, Ohio, between 1887-1938." *The Ohio Journal of Science*, 39, 275-288.
This article presents the results of fish sampling in two Ohio creeks in 1887 and

1938. The fish fauna changed between the sampling periods due to channelization and drainage projects. The undredged sections demonstrate little change between 1887 and 1938, but the dredged sections indicate a drastic change in the numerical abundance of fish species.

United States Coast Guard, Eighth District. 1976. *Greater New Orleans Mississippi River Bridge No. 2, Orleans Parish-Jefferson Parish, Louisiana, Draft Environmental Impact Statement.*
This document proposes that the impact to the ecology due to bridge construction will be minimal. The bridge approach area will require the removal of vegetation and the noise may temporarily disrupt the normal activities of the limited wildlife populations. Since the Mississippi River already has high levels of sediment and turbidity, the fish should not be severely impacted.

Van Hassel, J. H., J. J. Ney, and D. L. Garling, Jr. 1980. "Heavy metals in a stream ecosystem at sites near highways." *Transactions of the American Fisheries Society*, 109, 636-643.
Heavy metal concentrations in stream sediments, insects, and fish appear to be highly correlated to traffic density. "Stream sediments appear to serve as the storage reservoir and primary source for bioconcentration of heavy metals."

Wallen, I. E. 1951. "The direct effect of turbidity on fishes." *Bulletin of Oklahoma Agricultural and Mechanical College, Biological Series No. 2*, 48(2), Stillwater, Oklahoma, 1-27.
This article details the effects of and behavioral responses to montmorillonite clay turbidity on 380 fishes involving 16 species.

Welker, B. D. 1967. "Comparison of channel catfish populations in channeled and unchanneled sections of the Little Sioux River, Iowa." *The Proceedings of the Iowa Academy of Science*, 74, 99-104.
This study measured the abundance, movement, and age and growth of channel catfish in in channelized and unchannelized portions of an Iowa river. Only the abundance was higher in the unchannelized section of the river.

Wesche, T. A. 1985. "Stream channel modifications and reclamation structures to enhance fish habitat." In: *The Restoration of Rivers and Streams*, edited by J. A. Gore, Butterworth Publishers, Stoneham, Massachusetts, pp. 103-163.
This chapter offers "a brief review of the basic in-stream components of fish habit, the impacts of various channel modification activities on habitat diversity will be discussed...(and) channel restoration procedures and structures to enhance fish habitat."

Wharton, C. H. 1971. "Channelization impairs or destroys the terrestrial and aquatic wildlife resource base." *Proceedings on Stream Channelization*, pages 2189-2201, U. S. Congress, House of Representatives, Part IV, U. S. Government Printing Office, Washington, D. C., 3711 pp.

This paper discusses the detrimental impacts of channelization upon wildlife(fish, birds, plants, and invertebrates) in the Southeastern United States.

White, R. J. 1973. "Stream channel suitability for coldwater fish." ***Wildlife and Water Management: Striking a Balance,*** **Ankeny, Iowa, 7-24.**
This article reviews the impacts of channelization on coldwater fish (trout, salmon, and grayling). The channel characteristics which have positive and negative effects on fish are discussed in reference to channel alteration techniques.

Whitney, A. N. and J. E. Bailey. 1959. "Detrimental effects of highway construction on a Montana stream." ***Transactions of the American Fisheries Society,*** **88, 72-73.**
Briefly describes the negative impacts on fish populations due to the de-vegetating, scouring, and straightening of a Montana stream.

Wydoski, R. S. 1980. ***Effects of Alterations to Low Gradient Reaches of Utah Streams: Summary,*** **U. S. Fish and Wildlife Service, Office of Biological Services, FWS/OBS-80/13, 13 pp.**
This report summarizes the effects of stream channelization on fish and macroinvertebrates in Northern Utah. "Channelization adversely affected both fish and macroinvertebrate populations and biomass, with the severity of impact directly related to the amount and duration of disturbance of the physical habitat."

Wydoski, R. S. 1980. ***Effects of Alterations to Low Gradient Reaches of Utah Streams,*** **U. S. Fish and Wildlife Service, Office of Biological Services, FWS/OBS-80/14, 160 pp.**
This report describes the effects of stream channelization on fish and macroinvertebrates in the semi-arid intermountain region of Utah. "Channelization adversely affected both fish and macroinvertebrate populations and biomass, with the severity of impact directly related to the amount and duration of disturbance of the physical habitat."

Mitigation and/or Remediation Measures for Fish Impacts

Boussu, M. F. 1954. "Relationship between trout populations and cover on a small stream." ***Journal of Wildlife Management,*** **18(2), 229-239.**
This paper examines the relationship of trout populations to cover (natural and artificial) in a Montana stream. The addition of artificial cover caused a marked increase in numbers and pounds of fish while the removal of cover decreased the total pounds of fish and the number of larger specimens.

Bulkley, R. V., R. W. Bachmann, K. D. Carlander, H. L. Fierstine, L. R. King, B. W. Menzel, S. L. Witten, and D. W. Zimmer. 1976. ***Warmwater Stream Alteration in Iowa: Extent, Effects on Habitat, Fish, and Fish Food, and Evaluation of Stream Improvement Structures (Summary Report),*** **U. S. Fish and Wildlife Service, Biological Services Program, FWS/OBS-76/16, 39 pp.**

"This report summarizes the results given in 5 other subproject reports" regarding stream alteration in Iowa. The "differences in populations of fish and fish-food organisms in channelized and unchannelized streams, effects of stream alterations for highway bridge construction, and the value of stream-bank stabilization structures to fish habitat" are the topics covered.

Burkhard, W. T. 1967. "The effects of channelization on the trout fishery of Tomichi Creek." ***Colorado Fisheries Research Review No. 4*****, Fisheries Research Division, Colorado Department of Game, Fish, and Parks, Fort Collins, Colorado, 5-8.**
This paper evaluates the impacts of stream alteration on the trout fishery in the mountains of Colorado. Over the four year period the survey data failed to show any significant changes in the fishery. The channel was lined with large rocks and boulders and several were left in the stream.

Carline, R. F. and S. P. Klosiewski. 1981. ***Responses of Macroinvertebrates and Fish Populations to Channelization and Mitigation Structures in Chippewa Creek and River Styx, Ohio*****, The Ohio State University Research Foundation, Columbus, Ohio, 46 pp.**
"This study was designed to quantify the responses of fish populations to mitigation structures in two small warmwater streams" in Ohio. The streams had been channelized about 30 years ago. Double and single-wing deflectors were evaluated. Benthic organisms and fish populations responded positively to these mitigation structures.

Dane, B. G. 1978a. "A review and resolution of fish passage problems at culvert sites in British Columbia." ***Fisheries and Marine Service Technical Report No. 810*****, Department of Fisheries and Environment, Canada, 126 pp.**
This report analyzes the problems which culverts pose to fish in British Columbia. Design recommendations of culverts which should permit the free passage of fish under most circumstance are also presented.

Dane, B. G. 1978b. "Culvert guidelines: recommendations for the design and installation of culverts in British Columbia to avoid conflict with anadromous fish." ***Fisheries and Marine Service Technical Report No. 811*****, Department of Fisheries and Environment, Canada, 57 pp.**
This paper provides guidelines for proper design and installation of culverts in British Columbia to protect fish.

Dryden, R. L. and J. N. Stein. 1975. "Guidelines for the protection of fish resources of the Northwest Territories during highway construction and operation." ***Technical Report Series No. CEN/T-75-1*****, Environment Canada, Fisheries and Marine Service, Resource Management Branch, 32 pp.**
This report illustrates the problems encountered during highway construction in regards to fish resources in Canada. Recommendations for the design, construction, and operation of highways to protect fisheries are presented.

Edwards, C. J. 1977. *The Effects of Channelization and Mitigation on the Fish Community and Population Structure in the Olentangy River, Ohio*, Ph.D. Dissertation, Ohio State University, Columbus, Ohio, 161 pp.
This paper provides detailed information of the fish community in an Ohio river following channelization. The overall impact on community structure from channelization and mitigation was negative.

Elser, A. A. 1967. *Fish Populations of a Trout Stream in Relation to Major Habitat Zones and Channel Alterations*, M. S. Thesis, Montana State University, Bozeman, Montana, 26 pp.
This paper describes the fishery impacts of channel alteration in a Montana stream. Rock deflectors provided "physical characteristics comparable to unaltered sections, except vegetative cover."

Engel, P. 1974. "Fish passage facilities for culverts on the Mackenzie Highway." Environment Canada, National Water Research Institute, *Report prepared for the Environmental Working Group, Mackenzie Highway Project*, 67 pp.
This report evaluates the effectiveness of three different designs of fish passage facilities (spoilers, offset baffles, and side baffles) for culverts. Each is designed for to meet different streamflow criteria. "The effectiveness of all three designs is inversely proportional to the culvert slope. The maximum recommended slope is 5%." Suggestions concerning the shape of the culverts are also considered.

***Engineering News-Record*. 1994. "Sturgeon survive pier blast." 233, 17.**
The procedure used to demolish two underwater bridge piers in the Connecticut River while protecting the endangered snub-nosed sturgeon is described.

Funk, J. L. 1973. "Characteristics of channels for warmwater fisheries." *Wildlife and Water Management: Striking a Balance*, Ankeny, Iowa, 1-7.
This article describes the different types of gradient, pools, and riffles. The benefits of each type are discussed.

Gebhards, S. V. 1972. *Fish Passage and Culvert Installations.* Idaho Fish and Game Department, Boise, Idaho, 12 pp.
This paper describes the culvert installation policy in Idaho to provide adequate fish passage.

Gersmehl, J. and T. Meyers. No date. *Effects of Stream Channelization on Trout Populations of the White River, Vermont*, U. S. Fish and Wildlife Service, Fishery Assistance, Mont Pelier, Vermont, 39 pp.
This report evaluated the impacts of channelization on trout in a Vermont river. Stream alteration severely affected trout populations. "The average reduction in density for all trout species at all sites during 1974-1977 was approximately 50%." Recommendations are also made regarding alterations of trout streams.

Headrick, M. R. 1976b. *Effects of Stream Channelization on Fish Populations in the Buena Vista Marsh, Portage County, Wisconsin*, U. S. Fish and Wildlife Service, Office of Biological Services, FWS/OBS-76/24, 38 pp.
This paper compares fish populations from 6-8 year old and 52-62 year old ditches with populations of natural streams. Channelization reduced year-round instream cover, decreased substrate stability, and increased silt accumulation and stream temperatures. The impacts regarding these changes are discussed for several fish species. "Recovery was more rapid in ditches where spoil was spread on adjacent fields and bank vegetation left in place than in ditches where loose spoil was left on the banks." Recommendations for trout management of dredged streams are given.

Kay, A. R. and R. B. Lewis. 1970. *Passage of Anadromous Fish thru Highway Drainage Structures*, Highway Research Report, California Division of Highways, 27 pp.
This report presents a design procedure "which enables the engineer to determine if a given structure requires special consideration for fish passage."

Kennedy, H. D. 1955. "Colonization of a previously barren stream section by aquatic invertebrates and trout." *The Progressive Fish-Culturist*, 17, 119-122.
Results of a study involving the extent to which aquatic invertebrates and stream-resident brown trout colonized a previously barren portion of Convict Creek in California.

Knox, R. F and J. D. McCall. 1979. "Habitat mitigation in Indiana's authorized channelization projects." *The Mitigation Symposium: A National Workshop on Mitigating Loss of Fish and Wildlife Habitats*, July 16-20, Colorado State University, Fort Collins, Colorado, Rocky Mountain Forest and Range Experiment Station General Technical Report RM-65, 582-585.
This article describes the techniques being used in Indiana to protect riparian vegetation, and fish and wildlife habitat. The techniques include sediment traps, one-sided construction, low-impact debris removal, pool-riffle construction in bedrock, revegetation, shade maintenance, installation of fish pools with deflectors and constructed riffles in earth structures, fencing and vegetation markers, and wetland acquisition.

Kochman, E. 1979. "Channelization in Colorado--past, present, and future." *The Mitigation Symposium: A National Workshop on Mitigating Loss of Fish and Wildlife Habitats*, July 16-20, Colorado State University, Fort Collins, Colorado, Rocky Mountain Forest and Range Experiment Station General Technical Report RM-65, 586-589.
This article describes the Stream Protection Act of Colorado and its impacts on stream alteration projects. A stream relocation project is provided as an example of mitigating the impacts on the riparian ecosystem. Revegetation and aquatic habitat improvements were successful in this project.

Leedy, D. L. 1975. *Highway-Wildlife Relationships, Volume 1. A State-of-the-Art Report.* Federal Highway Administration, Report No. FHWA-RD-76-4, 183 pp.
This is an extensive literature review which "assesses what is known about highway-wildlife relationships and suggests research and management approaches to protect and enhance fish, wildlife, and environmental quality."

Lere, M. E. 1982. *The Long Term Effectiveness of Three Types of Stream Improvement Structures Installed in Montana Streams,* M. S. Thesis, Montana State University, Bozeman, Montana, 99 pp.
This study evaluated the effectiveness of random boulders, rock jetties, and log step dams in Montana streams. The boulders and rock jetties proved to be the most successful at restoring trout habitat in the long term.

Lund, J. A. 1976. *Evaluation of Stream Channelization and Mitigation on the Fishery Resource on the St. Regis River, Montana,* U. S. Fish and Wildlife Service, Biological Services Program, FWS/OBS-76/06, 49 pp.
Stream channelization effects on stream morphology and gamefish populations due to highway and railroad construction are presented. Mitigating structures (jetties and random rock clusters) were effective in providing fish habitat. Fish populations stabilized in about one year in new channels.

MacPhee, C. and F. J. Watts. 1976. *Swimming Performance of Arctic Grayling in Highway Culverts,* Final Report to U. S. Fish and Wildlife Service, Anchorage, Alaska, Bulletin No. 13, College of Forestry, Wildlife, and Range Sciences, University of Idaho, Moscow, Idaho, 41 pp.
This report evaluates the passage of Arctic graylings and longnose suckers through culverts in Alaska.

McClellan, T. J. 1974. *Ecological Recovery of Realigned Stream Channels,* U. S. Department of Transportation, Federal Highway Administration, Field Investigation Report, 78 pp.
This report determines the long-term effects of man-made channel changes on fish in Oregon. The natural recovery rate is assessed and methods are evaluated to minimize damage for future channel change projects. Recommendations are given to help minimize the impacts and facilitate the recovery from channel changes. The bulk of the report is Appendix A - Site Review Notes and Photographs of 18 different changed channel projects.

Metsker, H. E. 1970. "Fish versus culverts: some considerations for resource managers." *Engineering Technical Report, ETR-7700-5,* Forest Service, U. S. Department of Agriculture, 19 pp.
This paper presents problems that culverts impose upon fish. Design and reconstruction recommendations are presented to mitigate the impacts.

Mih, W. C. and G. C. Bailey. 1979. "A machine for mitigation of salmonid spawning habitat from silting." ***The Mitigation Symposium: A National Workshop on Mitigating Loss of Fish and Wildlife Habitats*****, July 16-20, Colorado State University, Fort Collins, Colorado, Rocky Mountain Forest and Range Experiment Station General Technical Report RM-65, 645-648.**
This paper describes "a machine developed to remove silt and sediments from spawning gravels." Several alternatives to reduce the detrimental effects of sediments are also presented which include reduce the source of sediments upstream, replace spawning beds with new gravel, mechanically disturb the beds to 'clean' the gravel, create a hydraulic disturbance by sluice gate action--baffle gate, and utilize a hydraulic flushing and suction system.

Montalbano, F., III, K. J. Foote, M. W. Olinde, and L. S. Perrin. 1979. "The Kissimmee River channelization: a preliminary evaluation of fish and wildlife mitigation measures." ***The Mitigation Symposium: A National Workshop on Mitigating Loss of Fish and Wildlife Habitats*****, July 16-20, Colorado State University, Fort Collins, Colorado, Rocky Mountain Forest and Range Experiment Station General Technical Report RM-65, 508-515.**
This paper determined that despite mitigation measures implemented during the channelization of a Florida river the fish and wildlife were negatively impacted.

Moulton, J. C. 1970. ***The Fishery Potential of Four Aquatic Environments Created by Interstate Route 91 Construction in Massachusetts*****, M. S. Thesis, University of Massachusetts, Amherst, Massachusetts, 86 pp.**
This paper examines the fishery potential of ponds created as a result of highway construction in Massachusetts. Three of the four ponds are suitable for fisheries and management recommendations are made for increasing the fishery potential. Construction and management guidelines are also presented for future borrow pit ponds.

Nunnally, N. R. 1978. "Improving channel efficiency without sacrificing fish and wildlife habitat: the case for stream restoration." ***Strategies for Protection and Management of Floodplain Wetlands and Other Riparian Ecosystems Symposium Proceedings*****, December 11-13, Callaway Gardens, Georgia, 394-399.**
This article describes an economically and environmentally satisfying solution to conventional channelization, which is stream restoration. This "creates a more stable channel by removing debris, providing fairly uniform cross sections, and stabilizing stream banks with minimal disturbance of the streambed and riparian vegetation."

Osborn, J. F. and J. W. Anderson. 1986. "Stream improvement and fish response: a bio-engineering assessment." ***Water Resources Bulletin*****, 22(3), 381-388.**
This article describes the positive and negative impacts of stream modifications upon fish. Stream improvements for restoring or enhancing fish habitats are discussed.

Otis, M. B. 1964. *Cooperation of the Engineer and Biologist as Related to Stream Improvement Practices*, New York State Conservation Department, Albany, New York, 10 pp.
This article describes the evolution of the design process of stream alteration projects. The section presenting suggested measures for minimizing damage to fishing streams from highway projects is quite informative.

Richard, J. A. 1963. *Long Stream Improvement Devices and Their Effects Upon the Fish Population, South Fork Mokelumne River, Calaveras County*, Inland Fisheries Administrative Report No. 63-7, State of California, The Resources Agency, Department of Fish and Game, 12 pp.
This report evaluates the improvement structures in a California stream. No significant beneficial results were achieved in this study. However, recommendations regarding structures are that "the structures installed should be of low elevation; single log; sheeting or rock contained with wire and not exceeding about 12 inches in height. The single log 'K' type structure was the most sturdy " in this study.

Riethman, D. T. 1992. "Impact of environmental features on completed channel modifications." Paper presentation at the International Winter Meeting of the American Society of Agricultural Engineers, Paper No. 92-2644, 12 pp.
This paper details the Little Auglaize River Watershed Project in Ohio. The project implemented construction methods and installed environmental features to mitigate the losses of fish and wildlife habitat. These features have had a positive impact on the environment and still provide the needed flood control.

Saltzman, W. and R. O. Koski. No date. *Fish Passage Through Culverts*, Special Report of the Oregon State Game Commission, 9 pp.
This paper states that when bridges are impractical the most desirable culvert is a structural steel arch set in concrete footings in regards to fish passage. Other preferable culvert designs are also discussed.

Sinning, J. A. and J. W. Andrew. 1979. Habitat enhancement for Colorado squawfish in the Yampa River in conjunction with railroad construction." *The Mitigation Symposium: A National Workshop on Mitigating Loss of Fish and Wildlife Habitats*, July 16-20, Colorado State University, Fort Collins, Colorado, Rocky Mountain Forest and Range Experiment Station General Technical Report RM-65, 553-555.
The Colowyo Coal Company decided to construct additional backwater habitat suitable for rearing Colorado squawfish despite no adverse impact of its intended railroad construction. "This paper discusses the design criteria and rational for the backwaters, proposed use, interactions with state and federal agencies and some of the problems arising from this habitat enhancement project."

United States Department of Transportation, Federal Highway Administration. 1979. *Restoration of Fish Habitat in Relocated Streams*, FHWA-IP-79-3, 63 pp.

This report provides rehabilitation measures for relocated streams in order to enhance the fishery and aesthetic values. A case study of a Colorado river is also discussed.

Warner, G. 1965. "Relocating a river and rebuilding a fishery." ***Outdoor California*, 26(1), 14-15.**
This is a brief article which describes the methods employed to reduce the negative impacts of a relocated stream channel in California.

Warner, K. and I. R. Porter. 1960. "Experimental improvement of a bulldozed trout stream in Northern Maine." ***Transactions of the American Fisheries Society*, 89(1), 59-63.**
This paper details the improvement of a stream in Maine using a bulldozer. The wing deflectors and spring holes were successful in creating trout habitat while the rock dams were largely unsuccessful.

Watts, F. J., P. Dass, C. P. Liou, and M. Harrison. 1973. ***Investigations of Culverts and Hydraulic Structures Used for Fishways and the Enhancement of Fish Habitat*, Research Technical Completion Report, Project A-027-IDA, Water Resources Research Institute, University of Idaho, Moscow, Idaho, 7 pp.**
This paper presents a method for the design of slot orifice fishways for box culverts. This research addressed the problems associated with fish passage through culverts.

Wesche, T. A. 1985. "Stream channel modifications and reclamation structures to enhance fish habitat." In: ***The Restoration of Rivers and Streams*, edited by J. A. Gore, Butterworth Publishers, Stoneham, Massachusetts, pp. 103-163.**
This chapter offers "a brief review of the basic in-stream components of fish habit, the impacts of various channel modification activities on habitat diversity will be discussed...(and) channel restoration procedures and structures to enhance fish habitat."

Wilkins, L. P. 1958. ***Construction and Evaluation of Stream Alteration Structures in North River on the Tellico Wildlife Management Area of Tennessee*, Tennessee Game and Fish Commission, 19 pp.**
This paper describes the stream alteration structures used to improve trout habitat in Tennessee. The four basic designs included the wedge dam, modified wedge dam, K-dam, and single-wing deflector. "A significant increase in young-of-the-year trout occurred while the standing crop of age-group I trout has gradually increased, in spite of greater fishing intensity in the improved area."

Witten, A. L. and R. V. Bulkley. 1975. ***A Study of the Effects of Stream Channelization and Bank Stabilization on Warm Water Sport Fish in Iowa: Subproject No. 2. A Study of the Impact of Selected Bank Stabilization Structures on Game Fish and Associated Organisms*, Iowa State Univ., Iowa State Conservation Commission, and U. S. Fish and Wildlife Service, 116 pp.**

This report investigates the effectiveness of four bank stabilization techniques (revetments, retards, permeable jetties, and impermeable jetties) at providing suitable habitat for aquatic organisms, particularly game fish.

Impacts of Stream Channel Modification on Invertebrates

Arner, D. H., H. R. Robinette, J. E. Frasier, and M. Gray. 1975. Effects of channel modification on the Luxapalila River." *Symposium on Stream Channel Modification Proceedings*, August 15-17, Harrisonburg, Virginia, 77-96.
Discusses biological data (turbidity, plankton, macroinvertebrates, fish, and furbearers) collected from an old channelized section, an unchannelized section, and a newly channelized section of the Luxapalila River in Mississippi.

Arner, D. H., H. R. Robinette, J. E. Frasier, and M. H. Gray. 1976. *Effects of Channelization of the Luxapalila River on Fish, Aquatic Invertebrates, Water, Quality, and Furbearers*, U. S. Fish and Wildlife Service, Office of Biological Services, FWS/OBS-76-08, 58 pp.
This paper presents data from an old channelized section (over 52 years), unchannelized section, and newly channelized section of a river in Mississippi and Alabama. Diversity of plankton, macroinvertebrates, and fish; average number/sample of fish and macroinvertebrates; and average weight of largemouth bass were all greater in the unchannelized section. The "productivity of the old channelized segment has not recovered to the levels exhibited in the unchannelized segment."

Baker, M., Jr., Inc. 1975. *Evaluation of the Environmental Impact to Appalachian Pennsylvania Waters of the 1972 Flood and Subsequent Stream Channelization with Future Policy Recommendations,* Report ARC-73-185-2562, PB 245 659, Prepared for Pennsylvania Fish Commission and Department of Environmental Resources, Harrisburg, Pennsylvania, 304 pp.
This extensive report evaluates the impacts of stream channelization on aquatic organisms in Pennsylvania. No long term effects were determined for the aufwuch communities and benthic invertebrates. Stream alteration is most detrimental to gamefish populations with varied recovery success.

Barber, W. E. and N. R. Kevern. 1973. "Ecological factors influencing macroinvertebrate standing crop distribution." *Hydrobiologia*, 43, 53-75.
"Influence of substrate, macrophyte growth, and detritus on macroinvertebrate standing crop (numbers and biomass) as well as seasonal variations in standing crop were investigated in a trout stream" in Pine River, Michigan.

Barton, B. A. 1977. "Short-term effects of highway construction on the limnology of a small stream in Southern Ontario." *Freshwater Biology*, 7, 99-108.
This paper evaluates the immediate impacts of the construction of a highway stream-crossing (culvert) in regard to suspended solids, sediments, water chemistry, fish standing crop, and macroinvertebrates.

Barton, J. R., D. A. White, P. V. Winger, and E. J. Peters. 1972. "The effects of highway construction on fish habitat in the Weber River, near Henefer, Utah." *Engineering Resources Centre, Colorado Bureau of Reclamation Report No. RCE-ERC-72-17*, 17-28.

This article evaluates the impacts (positive and negative) on fish due to highway construction in the Weber River, Utah. Six months after construction, the invertebrates had colonized the area and produced equivalent numbers and species. Fish populations returned to former levels two years after construction.

Barton, J. R. and P. V. Winger. 1973. *A Study of the Channelization of the Weber River, Summit County, Utah*, Report presented to the Utah Division of Wildlife Resources and Utah State Department of Highways, 188 pp.

This report analyses the impacts of channelization on the hydrologic aspects, aquatic invertebrates, and fisheries. A list of conclusions concerning channelization is also presented.

Benson, N. G. and A. S. Weithman. 1980. *Seven U. S. Fish and Wildlife Stream Channelization Studies*, National Water Resources Analysis Group, Eastern Energy Land Use Team, Office of Biological Services, Fish and Wildlife Service, 54 pp.

This report compiles information regarding stream channelization studies in eight states. "Effects on macroinvertebrate abundance and diversity, fish numbers and biomass, mammal and bird populations, reptile and amphibian abundance and diversity are all discussed. Recommendations for assessing impact and developing alternative measures in stream channelization are also discussed."

Bingham, A. E. 1977. *The Effects of Stream Channelization on Five Centrarchid Fishes in the Olentangy River, Ohio*, M. S. Thesis, Ohio State University, Columbus, Ohio, 75 pp.

This paper evaluates the effects of channelization on the growth and feeding of fish in an Ohio river. The overall effects of channelization and mitigation were minimal. The changes in the "macrobenthic community translated into differences in the composition and density of the sport fish community at each site, rather than into feeding and growth differences." Channelization has more of an impact on fish community dynamics than on feeding and growth.

Bradt, P. T. and G. E. Wieland III. 1978. *The Impact of Stream Reconstruction and a Gabion Installation on the Biology and Chemistry of a Trout Stream*, U. S. Department of the Interior, Office of Water Research and Technology, Completion Report, 62 pp.

This report evaluates the effect of a gabion installation and stream reconstruction in a rechanneled stream in Pennsylvania. In the rechanneled section, the algae populations; benthic diversity index, biomass, total numbers, and number of taxa; conductivity; dissolved oxygen; percent oxygen saturation; alkalinity; channel depth; and flow velocity increased significantly. Orthophosphate decreased significantly.

Brooker, M. P. 1985. "The ecological effects of channelization." *The Geographical Journal*, 151, 63-69.
This paper identifies the impacts which channelization in the UK has upon fish, macroinvertebrates, aquatic and bankside vegetation, birds, and mammals. Management conclusions are also presented.

Burns, J. W. 1972. "Some effects of logging and associated road construction on Northern California streams." *Transactions of the American Fisheries Society*, 101, 1-17.
Logging and road construction impacts of California streams are presented. "Extensive use of bulldozers in stream channels during debris removal caused excessive streambed sedimentation in narrow streams." Thinning the riparian canopy of streams can increase in the water temperature. In cold, shaded streams this can lead to an increase the production of algae, bacteria, and insects upon which fish feed. However, too much shade removal can also be detrimental to aquatic organisms.

Chisholm, J. L. and S. C. Downs. 1978. "Stress and recovery of aquatic organisms as related to highway construction along Turtle Creek, Boone County, West Virginia." *Geological Survey Water-Supply Paper 2055*, 40 pp.
This paper details the impacts and recovery rates of the benthic organisms in a West Virginia stream after highway construction. The benthic community of the effected stream was similar to that of the control stream one year after highway construction was completed.

Chutter, F. M. 1969. "The effects of silt and sand on the invertebrate fauna of streams and rivers." *Hydrobiologia*, 34, 57-76.
This paper is a literature review concerning the effects of silt and sand on the invertebrates in South African watercourses. "It is concluded that there may be considerable changes in the composition of the stones in current fauna due to silt and sand without the biotope being smothered, and that increases in the amount of silt and sand in river beds lead to increased instability of the sediments, which adversely affects their fauna."

Cline, L. D., R. A. Short, and J. V. Ward. 1982. "The influence of highway construction on the macroinvertebrates and epilithic algae of a high mountain stream." *Hydrobiologia*, 96, 149-159.
This paper reports the response of a Rocky Mountain stream to highway construction. "The severity of the response was a function of the flow regime and the timing and duration of the impact at a given site. The hydrologic regime and high gradient of the study stream appeared to ameliorate to some extent the potentially adverse effects of short-term perturbations engendered by highway construction activities."

Cline, L. D., R. A. Short, J. V. Ward, C. A. Carlson, and H. L. Gary. 1983. "Effects of highway construction on water quality and biota in an adjacent Colorado mountain stream." Research Note RM-429, 10 pp.

The impacts of highway construction upon a Colorado stream are detailed. "Highway construction increased total suspended solids and channel sedimentation, while other water quality variables (total dissolved solids, organic fraction of dissolved solids, organic fraction of suspended solids, dissolved oxygen, free and bound carbon dioxide, pH, temperature, and discharge) were unaffected in and adjacent, high elevation stream. Epilithon standing crop and macroinvertebrate density decreased and compositional changes were noted. Effects were more pronounced in depositional areas. No change in fish condition was detected."

Dodge, W. E., E. E. Possardt, R. J. Reed, and W. P. MacConnell. 1976. *Channelization Assessment, White River, Vermont: Remote Sensing, Benthos, and Wildlife*, U. S. Fish and Wildlife Service, Office of Biological Services, FWS/OBS-76-07, 73 pp.
This report evaluates the impacts of channelization on benthos and wildlife of a Vermont river. After 8 months there was no significant difference in the benthic organisms of channelized and unchannelized areas. The majority of songbirds and small mammals were captured in the unchannelized areas, which also had the greatest species diversity. "No gross differences were observed between channelized and control (non-channelized) sites for the furbearers and amphibians. The most drastic impact on wildlife occurred at channelized sites where streamside vegetation was the most extensively destroyed."

Etnier, D. A. 1972. "The effect of annual rechanneling on a stream fish population." *Transactions of the American Fisheries Society*, 101(2), 372-375.
The impacts of channeling a Tennessee stream for flood control purposes is discussed. The fish fauna was significantly changed and the invertebrate diversity decreased.

Forshage, A. and N. E. Carter. 1973. "Effects of gravel dredging on the Brazos River." *Proceedings of the 24 th Annual Conference of Southeastern Association of Game and Fish Commissioners*, 24, 695-708.
This paper discusses the physicochemical and biological changes of the Brazos River following a gravel dredging operation and the effects on the river fauna. The study concluded "that gravel operations can influence stream substrate type, reduce the abundance of bottom-dwelling invertebrates, and change fish populations to favor less desirable species."

Griswold, B. L., C. Edwards, L. Woods, and E. Weber. 1978. *Some Effects of Stream Channelization on Fish Populations, Macroinvertebrates, and Fishing in Ohio and Indiana*, U. S. Fish and Wildlife Service, Biological Services Program, FWS/OBS-77/46, 64 pp.
"The effects of stream channelization on warm water fish and macroinvertebrate population were studied in five streams by comparing the biota in natural areas to that in nearby channelized areas...In general, channelization adversely affected

macrobenthos diversity, abundance, and/or biomass, and it caused a shift in species composition from riffle species to less desirable standing water burrowing forms...The biota of the mitigated area...approximated that of the natural area."

Hamilton, J. D. 1961. "The effect of sand-pit washings on a stream fauna." International Association of Theoretical and Applied Limnology, 14, 435-439.
This paper reports that the impacts of sediments upon the bottom fauna and fish are minimal and recolonization of affected areas occurred six months after the sediments were reduced.

Hansen, D. R. 1971a. *Effects of Stream Channelization on Fishes and Bottom Fauna in the Little Sioux River, Iowa*, M. S. Thesis, Iowa State University, Ames, Iowa, 119 pp.
This paper evaluates the differences in physical factors, bottom fauna, and fish populations in channelized and unchannelized portions of an Iowa river. The channelized section produced greater daily water temperature fluctuations and higher turbidities. "Results of the investigation revealed certain differences in bottom fauna and fish fauna between the two sections of the river." Channel catfish proved to be an excellent indicator of the channelized conditions. "Conditions in the channelized section were not as favorable for stable populations of larger game fishes."

Hansen, D. R. 1971b. "Stream channelization effects on fishes and bottom fauna in the Little Sioux River, Iowa." *Stream Channelization: A Symposium*, North Central Division American Fisheries Society Special Publication No. 2, Eds. E. Schneberger and J. L. Funk, 29-51.
This paper describes the differences in certain physical factors, bottom fauna, and fish populations in channelized and unchannelized portions of an Iowa river. Water temperatures, temperature fluctuations, and turbidities were higher in the channelized section. Composition of bottom fauna was similar in both sections. Numbers of fish species was greater in the unchannelized section. Lack of suitable habitat was the most obvious cause for the fish differences.

Hansen, D. R. and R. J. Muncy. 1971. "Effects of stream channelization on fishes and bottom fauna in the Little Sioux River, Iowa." Completion Report of Project No. A-035-IA, Iowa State Water Resources Research Institute, 118 pp.
This paper reports the findings of a study which evaluated the differences in certain physical factors, bottom fauna, and fish populations in channelized and unchannelized portions of the Little Sioux River, Iowa, occurring 1969-71.

Hortle, K. G. and P. S. Lake. 1982. "Macroinvertebrate assemblages in channelized and unchannelized sections of the Bunyip River, Victoria." *Australian Journal of Marine and Freshwater Research*, 33, 1071-1082.
This paper presents the results of a study conducted in Australian streams. "There were no consistent differences in species richness, density, and standing crop of the macroinvertebrates between sites...The most important factor affecting density,

standing crop, and species richness was substratum stability, which if decreased by channelization, is likely to reduce the abundance and species richness of resident macroinvertebrate assemblages."

Keefer, L. C. 1977. *The Effects of Headwater Reservoirs and Channelization on Invertebrate Drift in Piedmont Streams*, M. S. Thesis, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, 121 pp.
This paper examines the impacts of channelization on the invertebrate fauna in Virginia. "Channelized streams tended to h ave higher drift densities and lower benthic standing crop densities than unchannelized streams."

King, D. L. and R. C. Bell. 1964. "Influence of highway construction on a stream." *Research Report 19, Michigan State University, Agricultural Experiment Station, East Lansing*, 4 pp.
This is an evaluation of destruction of natural stream environment by channel realignment. Effects on the aufwuchs (basic producers), invertebrates, fish, and stream energetics are discussed.

Langemeier, R. M. 1965. *Effects of Channelization on the Limnology of the Missouri River, Nebraska, with Emphasis on Food Habits and Growth of the Flathead Catfish*, M. A. Thesis, University of Missouri, Columbia, MO, 156 pp.
This paper evaluates the limnological differences in channelized and unchannelized portions of the Missouri River. The chemical properties were similar. The growth rates of the flathead catfish was slower in the unchannelized section. Invertebrate drift was a good index for catfish growth. "The difference in the abundance of aufwuchs and the difference in the degree of aggregation of these organisms is assumed to be the reason for the difference in size of young-of-the-year flathead catfish between the two stations.

Lenat, D. R., D. L. Penrose, and K. W. Eagleson. 1981. "Variable effects of sediment addition on stream benthos." *Hydrobiologia*, 79, 187-194.
This article identified the responses of stream benthos to road construction-produced sediments under high and low flow conditions. Under high flow conditions benthic diversity decreases with little change in the community structure. While density increases and community structure is distinctly changed during low flow conditions.

Marzolf, G. R. 1978. *The Potential Effects of Clearing and Snagging on Stream Ecosystems*, U. S. Fish and Wildlife Service, Biological Services Program, FWS/OBS-78/14, 31 pp.
This report "identifies some potential ecological impacts of clearing and snagging, but does not yield quantitative predictions of the impacts." The effects of clearing and snagging on primary producers, decomposition, organic matter processing, macroinvertebrates, and fish are discussed.

Minshall, G. W. and P. V. Winger. 1968. "The effect of reduction in stream flow on the invertebrate drift." *Ecology*, 49, 580-582.

Invertebrate drift is evaluated with regard to stream flow variation. "Artificial reduction of stream discharge resulted in an increase in benthic invertebrates in the drift. Virtually all bottom-dwelling forms were affected. Entry into the drift seemed an active process initiated by changes in current velocity and depth, and resulting in reversal of the normal avoidance response to light."

Morris, L. A., R. N. Langemeier, T. R. Russell, and A. Witt, Jr. 1968. "Effects of main stem impoundments and channelization upon the limnology of the Missouri River, Nebraska." *Transactions of the American Fisheries Society*, 97(4), 380-388.
This paper examines the impacts of impoundment and channelization of a Nebraska river. "Channelization of the river has reduced both the size and variety of aquatic habitat by destroying key productive areas." The significant change in the benthic standing crop of drift was attributed to the channelization.

Moyle, P. B. 1976. "Some effects of channelization on the fishes and invertebrates of Rush Creek, Modoc County, California." *California Fish and Game*, 62(3), 179-186.
This paper examines the differences in fish and invertebrate populations due to channelization in a California stream. "Overall, total fish biomass in the channelized sections was less than one-third of that in the unchannelized sections. The biomass of invertebrates in the channelized sections was found to be less than one-third of that in the unchannelized sections."

Murphy, M. L., C. P. Hawkins, and N. H. Anderson. 1981. "Effects of canopy modification and accumulated sediment pollution on stream communities associated with clear-cut logging in the Western Cascade Range of Oregon." *Transactions of the American Fisheries Society*, 110, 469-478.
The impacts of canopy modification and increased sediments on a stream in Oregon are presented. "Streams traversing open clear-cuts had greater rates of microbial respiration, and greater densities or biomasses of aufwuchs, benthos, drift, salamanders, and trout than did the shaded, forested sites regardless of sediment composition. It is concluded that for these small Cascade Range streams, changes in trophic status and increased primary productivity resulting from shade removal may mask or override effects of sedimentation."

Ogbeibu, A. E. and R. Victor. 1989. "The effects of road and bridge construction on the bank-root macrobenthic invertebrates of a Southern Nigerian stream." *Environmental Pollution*, 56, 85-100.
This article presents the results of a comparative study on a fourth order Nigerian stream to evaluate the effects of a road and bridge construction on the macrobenthic invertebrates of the bank-root biotope. "Siltation and sedimentation appear to be the important factors affecting macroinvertebrates." Construction did not affect the chemical characteristics of the stream.

Pilli, A., D. O. Carle, E. Kline, Q. Pickering, and J. Lazorchak. 1988. "Effects of pollution on freshwater organisms." ***Journal of the Water Pollution Control Federation*****, 60(6), 994-1065.**
This is a very extensive literature review of the impacts of pollutants (toxic chemicals, effluents, leachates, oils, and pH effects) on freshwater organisms (fish, invertebrates, and algae.)

Porter, T. R., D. M. Rosenberg, and D. K. McGowan. 1974. ***Winter Studies of the Effects of a Highway Crossing on the Fish and Benthos of the Martin River, N. W. T.*****, Environment Canada, Fisheries and Marine Service Technical Report Series No. CEN/T-74-3, 50 pp.**
This report details the impacts of a highway crossing on the fish and benthos of a Canadian river. "There was no clear indication that the Martin River highway crossing and related winter activities had any discernible effects on the fish and benthic fauna through the winter of 1972-1973."

Rabeni, C. F. and G. W. Minshall. 1977. "Factors affecting microdistribution of stream benthic insects." ***Oikos*****, 29, 33-43.**
The results of "the microdistribution of stream insects in relation to current velocity, substratum, particle size, silt, and detritus studied in field experiments utilizing substratum-filled trays" are presented in this paper.

Reed, J. R. 1977. "Stream community response to road construction sediments." ***Virginia Water Resources Research Center Bulletin 97*****, 61 pp.**
"This publication summarizes a two-year study in the effectiveness of erosion-control measures, the effect of silt on macrobenthic and fish populations, and the ability of these populations to recover from stream degradation."

Rees, W. H. 1959. "Effects of stream dredging on young silver salmon (*Oncorhynchus kisutch*) and bottom fauna." ***Fisheries Research Papers*****, Washington Department of Fisheries, Seattle, Washington, 2(2), 53-65.**
This paper evaluates the biological changes in a Washington stream due to rechanneling operations. The bottom fauna "recovered completely" within 11 months after dredging. Silver salmon "population estimates made a year later compared favorably in test and control areas with estimates made" prior to dredging.

Sanders, D. F. 1976. ***Effects of Stream Channelization on Aquatic Macroinvertebrates, Buena Vista Marsh, Portage County, Wisconsin*****, M. S. Thesis, University of Wisconsin, Stevens Point, 93 pp.**
This paper examines the differences in benthic macroinvertebrates in channelized and unchannelized sections of a stream in Wisconsin. The differences in substrate composition was the primary reason for differences in benthic biomass and density. "Higher numbers of invertebrate taxa were collected from natural streams and lower numbers of taxa from new ditches...Numbers of drifting taxa were highest in the upstream new ditch and downstream natural stream, which were the sites with the highest sand substrate composition in their respective areas. Water temperatures

were similar in ditches and natural streams.many measured chemical parameters were similar on did not exhibit consistent trends."

Schmal, R. N. 1978. *Effects of Stream Channelization on Aquatic Macroinvertebrates, Buena Vista Marsh, Portage County, Wisconsin*, M. S. Thesis, University of Wisconsin, Stevens Point, Wisconsin, 153 pp.
This study assesses the "effects of channelization on density and biomass of benthic and drifting macroinvertebrates, amount of drifting seston, and water temperature chemistry" in a Wisconsin marsh. The substrate most strongly influenced the macroinvertebrate populations. "When vegetation and silt-detritus were predominant, invertebrate populations were high; when substrate was largely shifting sand and unstable silt-detritus, invertebrate populations were low." Invertebrates drift was significantly affected. Temperature and chemistry did not vary greatly.

Schmal, R. N. and D. F. Sanders. 1978. *Effects of Stream Channelization on Aquatic Macroinvertebrates, Buena Vista Marsh, Portage County, Wisconsin*, U.S. Fish and Wildlife Service, Biological Services Program, FWS/OBS-78/92, 80 pp.
This report assesses the "effects of channelization on density and biomass of benthic and drifting macroinvertebrates, amount of drifting seston, and water temperature and chemistry in Wisconsin...Substrate strongly influenced macroinvertebrate populations...Channelization affected macroinvertebrate populations by creating unstable substrate conditions...Channelization appeared to affect invertebrate drift through its influence on drifting seston and benthos...Water temperature and chemistry did not differ greatly among the natural streams and ditches."

Smith, M. E. and J. L. Kaster. 1983. "Effect of rural highway runoff on stream benthic macroinvertebrates." *Environmental Pollution*, 32, 157-170.
This paper presents the impacts of runoff on benthic macroinvertebrate abundance and composition in Southeastern Wisconsin. "Disruption of benthic invertebrate communities by rural highway runoff was seen to be negligible. Significant difference in density, biomass, richness, and other parameters at stations affected by highway runoff, except those that could be explained by differences in physical stream parameters, were not evident."

Spence, J. A. and H. B. N. Hynes. 1971. Differences in benthos upstream and downstream of an impoundment." *Journal of the Fisheries Research Board of Canada*, 28, 35-43.
This article details the pronounced differences in the macroinvertebrate fauna upstream and downstream of a flood control impoundment. Reasons for the differences are also reviewed.

Swedberg, S. E. and Nevala. 1965. "Evaluation of fish habitat destruction in Little prickly Pear Creek due to construction of Interstate Highway 15." Montana Fish and Game Department, *Job Completion Report, F-5-R-14*, 11 pp.
This paper presents the data for temperature, water quality and quantity, bottom

fauna, and fish for the creek in graphs and tables. This is a preliminary investigation that does not provide any conclusions and the only recommendation is to continue the study.

Tsui, P. T. P. and P. J. McCart. 1981. "Effects of stream-crossing by a pipeline on the benthic macroinvertebrate communities of a small mountain stream." *Hydrobiologia*, 79, 271-276.
"Aquatic environmental impact associated with stream-crossing by pipeline was monitored at Archibald Creek, British Columbia for two years. Water chemistry and benthic macroinvertebrates were used as monitoring tools. Results indicated that impacts arising from stream-crossing were short-term and non-residual."

Van Hassel, J. H., J. J. Ney, and D. L. Garling, Jr. 1980. "Heavy metals in a stream ecosystem at sites near highways." *Transactions of the American Fisheries Society*, 109, 636-643.
Heavy metal concentrations in stream sediments, insects, and fish appear to be highly correlated to traffic density. "Stream sediments appear to serve as the storage reservoir and primary source for bioconcentration of heavy metals."

Wene, G. and E. L. Wickliff. 1940. "Modification of a stream bottom and its effect on the insect fauna." *The Canadian Entomologist*, 72, 131-135.
Constructed wire baskets were filled with various types of bottom materials and the insect populations evaluated for each different substratum type.

Wharton, C. H. 1971. "Channelization impairs or destroys the terrestrial and aquatic wildlife resource base." *Proceedings on Stream Channelization*, pages 2189-2201, U. S. Congress, House of Representatives, Part IV, U. S. Government Printing Office, Washington, D. C., 3711 pp.
This paper discusses the detrimental impacts of channelization upon wildlife(fish, birds, plants, and invertebrates) in the Southeastern United States.

Whitaker, G. A., R. H. McCuen, and J. Brush. 1979. "Channel modification and macroinvertebrate community diversity in small streams." *Water Resources Bulletin*, 15(3), 874-883.
"The principal objective of this study was to investigate the long-term, temporal effect of channel modification in the diversity of macroinvertebrates" of the Delmarva River, Maryland. "Correlation analyses suggest that aquatic macroinvertebrate communities stabilize shortly after channel modification."

White, T. R. 1980. *Recolonization of Streams by Aquatic Insects Following Channelization*, Technical Report No. 87, Volume I, Clemson University Water Resources Research Institute, 120 pp.
This paper presents the effects of channelization on the aquatic insects of North Carolina streams. Species composition and diversity were examined. It was determined that even 21 years after channelization the aquatic insect fauna had not recovered in terms of being similar to the unchannelized streams. Recommendations were also presented to minimize the impacts.

Winger, P. V. 1972. *The Effects of Channelization and Water Impoundment on the Macroinvertebrates in the Weber River, Summit County, Utah*, Ph.D. Dissertation, Brigham Young University, Salt Lake City, Utah, 111 pp.
This paper evaluates the impacts of road construction on the benthic invertebrates in a Utah river. "The effects of channelization on the macroinvertebrates fauna in the Weber River were negligible, but water impoundment influenced the species composition and species diversities of the populations occurring in the tailwater."

Wolf, J., J. McMahon, and M. Diggins. 1972. "Comparison of benthic organisms in semi-natural and channelized portions of the Missouri River." *Proceedings of the South Dakota Academy of Science*, 51, 160-167.
This paper concludes that channelization is detrimental to the benthic organisms of the Missouri River. While the diversity is nearly the same for both sections of the river, the density of benthic organisms in the semi-natural section is considerably higher than the channelized portion.

Woods, L. C., III. 1977. *The Effect of Stream Channelization and Mitigation on Warmwater Macroinvertebrate Communities*, M. S. Thesis, Ohio State University, Columbus, Ohio, 80 pp.
This paper evaluates the impacts of channelization on macroinvertebrate communities and examines the effectiveness of stream improvement structures in an Ohio river. Significant differences occurred in diversity and density of macroinvertebrates due to channelization. Even though mitigative actions proved successful channelized sections did not "seem to provide the stability necessary to maintain the diverse communities as found in the natural area."

Wydoski, R. S. 1980. *Effects of Alterations to Low Gradient Reaches of Utah Streams: Summary*, U. S. Fish and Wildlife Service, Office of Biological Services, FWS/OBS-80/13, 13 pp.
This report summarizes the effects of stream channelization on fish and macroinvertebrates in Northern Utah. "Channelization adversely affected both fish and macroinvertebrate populations and biomass, with the severity of impact directly related to the amount and duration of disturbance of the physical habitat."

Wydoski, R. S. 1980. *Effects of Alterations to Low Gradient Reaches of Utah Streams*, U. S. Fish and Wildlife Service, Office of Biological Services, FWS/OBS-80/14, 160 pp.
This report describes the effects of stream channelization on fish and macroinvertebrates in the semi-arid intermountain region of Utah. "Channelization adversely affected both fish and macroinvertebrate populations and biomass, with the severity of impact directly related to the amount and duration of disturbance of the physical habitat."

Zimmer, D. W. and R. W. Bachmann. 1976. *A Study of the Effects of Stream Channelization and Bank Stabilization on Warmwater Sport Fish in Iowa: Subproject No. 4. The Effects of Long-Reach Channelization on Habitat and Invertebrate Drift in Some Iowa Streams*, U. S. Fish and Wildlife Service, Biological Services Program, FWS/OBS-76/14, 87 pp.
This report presents the relationships between channel morphometry, habitat diversity, and invertebrate drift density in Iowa streams. "The impact of channelization on habitat diversity and invertebrate drift density might be minimized if channels were designed with greater sinuosity index values."

Zimmer, D. W. and R. W. Bachmann. 1978. "Channelization and invertebrate drift in some Iowa streams." *Water Resources Bulletin*, 14(4), 868-883.
This study examined the habitat diversity and invertebrate drift in channelized and natural tributaries of the Des Moines River. "Channelization has decreased habitat variability and invertebrate drift density in streams of the upper Des Moines River Basin and probably has reduced the quantity of water stored in streams during periods of low flow."

Mitigation and/or Remediation Measures for Invertebrate Impacts

Carline, R. F. and S. P. Klosiewski. 1981. *Responses of Macroinvertebrates and Fish Populations to Channelization and Mitigation Structures in Chippewa Creek and River Styx, Ohio*, The Ohio State University Research Foundation, Columbus, Ohio, 46 pp.
"This study was designed to quantify the responses of fish populations to mitigation structures in two small warmwater streams" in Ohio. The streams had been channelized about 30 years ago. Double and single-wing deflectors were evaluated. Benthic organisms and fish populations responded positively to these mitigation structures.

Gore, J. A. 1985. "Mechanisms of colonization and habitat enhancement for benthic macroinvertebrates in restored river channels." In: *The Restoration of Rivers and Streams*, edited by J. A. Gore, Butterworth Publishers, Stoneham, Massachusetts, pp. 81-101.
This chapter provides information "on the dispersal mechanisms of aquatic invertebrates, measurements of optimum habitat for invertebrates, and a synopsis of some typical reclamation efforts designed for macroinvertebrate habitat."

Kennedy, H. D. 1955. "Colonization of a previously barren stream section by aquatic invertebrates and trout." *The Progressive Fish-Culturist*, 17, 119-122.
Results of a study involving the extent to which aquatic invertebrates and stream-resident brown trout colonized a previously barren portion of Convict Creek in California.

White, T. R. 1980. *Recolonization of Streams by Aquatic Insects Following Channelization*, Technical Report No. 87, Volume I, Clemson University Water Resources Research Institute, 120 pp.

This paper presents the effects of channelization on the aquatic insects of North Carolina streams. Species composition and diversity were examined. It was determined that even 21 years after channelization the aquatic insect fauna had not recovered in terms of being similar to the unchannelized streams. Recommendations were also presented to minimize the impacts.

Woods, L. C., III. 1977. *The Effect of Stream Channelization and Mitigation on Warmwater Macroinvertebrate Communities*, M. S. Thesis, Ohio State University, Columbus, Ohio, 80 pp.
This paper evaluates the impacts of channelization on macroinvertebrate communities and examines the effectiveness of stream improvement structures in an Ohio river. Significant differences occurred in diversity and density of macroinvertebrates due to channelization. Even though mitigative actions proved successful channelized sections did not "seem to provide the stability necessary to maintain the diverse communities as found in the natural area."

Impacts of Stream Channel Modification on Mammals

Anderson, B. W. and R. D. Ohmart. 1985. "Riparian revegetation as a mitigating process in streams and river restoration." In: *The Restoration of Rivers and Streams*, edited by J. A. Gore, Butterworth Publishers, Stoneham, Massachusetts, pp. 41-80.
This chapter summarizes the results of field studies of riparian habitats on the lower Colorado River (Arizona) in which efforts were made to develop plant community designs, based on field-collected data, that would house as many vertebrate species, particularly birds and rodents, as possible and support high densities of wildlife. Costs of revegetation are also presented.

Arner, D. H., H. R. Robinette, J. E. Frasier, and M. Gray. 1975. Effects of channel modification on the Luxapalila River." *Symposium on Stream Channel Modification Proceedings*, August 15-17, Harrisonburg, Virginia, 77-96.
Discusses biological data (turbidity, plankton, macroinvertebrates, fish, and furbearers) collected from an old channelized section, an unchannelized section, and a newly channelized section of the Luxapalila River in Mississippi.

Barclay, John S. 1980. *Impact of Stream Alterations on Riparian Communities in Southcentral Oklahoma*, U. S. Fish and Wildlife Service, Biological Services Program, FWS/OBS-80/17, 91 pp.
This report details the impacts of stream alteration in the grasslands of Oklahoma. "Conclusions and recommendations are given on the effects of stream alteration to riparian vegetation and associated bird, mammal, amphibian, and reptile populations."

Benson, N. G. and A. S. Weithman. 1980. *Seven U. S. Fish and Wildlife Stream Channelization Studies*, National Water Resources Analysis Group, Eastern Energy Land Use Team, Office of Biological Services, Fish and Wildlife Service, 54 pp.

This report compiles information regarding stream channelization studies in eight states. "Effects on macroinvertebrate abundance and diversity, fish numbers and biomass, mammal and bird populations, reptile and amphibian abundance and diversity are all discussed. Recommendations for assessing impact and developing alternative measures in stream channelization are also discussed."

Brooker, M. P. 1985. "The ecological effects of channelization." ***The Geographical Journal*****, 151, 63-69.**
This paper identifies the impacts which channelization in the UK has upon fish, macroinvertebrates, aquatic and bankside vegetation, birds, and mammals. Management conclusions are also presented.

Dodge, W. E., E. E. Possardt, R. J. Reed, and W. P. MacConnell. 1976. ***Channelization Assessment, White River, Vermont: Remote Sensing, Benthos, and Wildlife*****, U. S. Fish and Wildlife Service, Office of Biological Services, FWS/OBS-76-07, 73 pp.**
This report evaluates the impacts of channelization on benthos and wildlife of a Vermont river. After 8 months there was no significant difference in the benthic organisms of channelized and unchannelized areas. The majority of songbirds and small mammals were captured in the unchannelized areas, which also had the greatest species diversity. "No gross differences were observed between channelized and control (non-channelized) sites for the furbearers and amphibians. The most drastic impact on wildlife occurred at channelized sites where streamside vegetation was the most extensively destroyed."

Ellis, R. W. 1976. ***The Impact of Stream Alteration on Wildlife along Tributaries of the Roanoke River, Charlotte County, Virginia*****, M. S. Thesis, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, 105 pp.**
This is a "comparative study of three different-aged channelized streams--3, 6, and 10 years after channelization--and an unchannelized stream (in Virginia). The relative composition of the stream side vegetation, and the abundance of small mammals and larger mammals, and the composition of winter and breeding birds was determined for each study site and compared to one another to determined the influence of stream channelization upon wildlife and their habitats." This is a good reference regarding successional processes along channelized rivers.

Ferguson, H. L. 1975. ***The Impact os Stream Alteration on Wildlife along Tributaries of the Roanoke River, Charlotte County, Virginia*****, M. S. Thesis, Virginia Polytechnic Institute and State University, Blacksburg, VA, 114 pp.**
This is a comparative study of three different-aged channelized streams (2, 5, and 9 years after channelization) in Virginia. "Species diversity of the vegetation, small mammals, and birds increased progressively from the 2 year old stream to the 9 year old stream." The most recently altered streams appeared to have unstable environments as indicated by lower and more variable species diversity and equitability values.

Hedrick, R. D. 1975. ***Impact of Channelization and Associated Land Use Changes on Wildlife Habitat,*** **M. S. Thesis, Oklahoma State University, Stillwater, Oklahoma, 46 pp.**
This paper details the detrimental impacts of channelization along an Oklahoma stream. The wildlife populations in the area have been negatively impacted.

Possardt, E. E. 1975. ***The Effects of Stream Channelization on Aquatic and Riparian Wildlife in the White River Watershed, Vermont,*** **M. S. Thesis, University of Massachusetts, Amherst, 84 pp.**
This paper documents the specific impacts of channelization on songbirds, small mammals, furbearers, reptiles, and amphibians in Vermont.

Possardt, E. E. and W. E. Dodge. 1978. "Stream channelization impacts on songbirds and small mammals in Vermont." ***Wildlife Society Bulletin,*** **6, 18-24.**
The birds and small mammals were significantly impacted by the channelization of a Vermont stream. "The most drastic impact on small mammal and songbird population occurred at the channelized sites where streamside vegetation had been extensively destroyed."

Prellwitz, D. M. 1976. ***Effects of Stream Channelization on Terrestrial Wildlife and Their Habitats in the Buena Vista Marsh, Wisconsin,*** **M. S. Thesis, University of Wisconsin, Stevens Point, Wisconsin, 113 pp.**
This paper evaluates the plant and animal species composition and abundance in regards to plant successional stages from grassland to mature woods adjacent to recently dredged (6 years), old dredged (50 years), and natural streams in Wisconsin. "Bird and mammal species diversity and bird abundance increased as plant succession advanced, until a mature wooded stage was reached. Abundance of small mammals was related to the amount of ground cover and the diversity of habitats along the stream banks. Reptile and amphibian species diversity was greatest along natural and old dredged streams having partially submerged branches and low-lying, moist areas...Waterfowl use, bird nesting, and reptile and amphibian abundance also were greatest on the undrained area"

United States Coast Guard, Eighth District. 1976. ***Greater New Orleans Mississippi River Bridge No. 2, Orleans Parish-Jefferson Parish, Louisiana, Draft Environmental Impact Statement.***
This document proposes that the impact to the ecology due to bridge construction will be minimal. The bridge approach area will require the removal of vegetation and the noise may temporarily disrupt the normal activities of the limited wildlife populations. Since the Mississippi River already has high levels of sediment and turbidity, the fish should not be severely impacted.

Vandre, W. G. 1975. ***Effects of Channel Redredging on Wildlife and Wildlife Habitat of Buena Vista Marsh,*** **M. S. Thesis, University of Wisconsin, Stevens Point, 87 pp.**

This paper examines the impacts of channel redredging on wildlife and their habitat in Wisconsin. Vegetation, waterfowl, non-game birds, and mammals are evaluated for impacts. Vegetation diversity was limited on recently channelized banks. Appropriate areas for waterfowl breeding were also reduced by channelization. The non-game bird and mammal species found along the ditch banks were associated with the diversity of vegetative cover.

Impacts of Stream Channel Modification on Reptiles

Barclay, John S. 1980. *Impact of Stream Alterations on Riparian Communities in Southcentral Oklahoma*, U. S. Fish and Wildlife Service, Biological Services Program, FWS/OBS-80/17, 91 pp.
This report details the impacts of stream alteration in the grasslands of Oklahoma. "Conclusions and recommendations are given on the effects of stream alteration to riparian vegetation and associated bird, mammal, amphibian, and reptile populations."

Benson, N. G. and A. S. Weithman. 1980. *Seven U. S. Fish and Wildlife Stream Channelization Studies*, National Water Resources Analysis Group, Eastern Energy Land Use Team, Office of Biological Services, Fish and Wildlife Service, 54 pp.
This report compiles information regarding stream channelization studies in eight states. "Effects on macroinvertebrate abundance and diversity, fish numbers and biomass, mammal and bird populations, reptile and amphibian abundance and diversity are all discussed. Recommendations for assessing impact and developing alternative measures in stream channelization are also discussed."

Possardt, E. E. 1975. *The Effects of Stream Channelization on Aquatic and Riparian Wildlife in the White River Watershed, Vermont*, M. S. Thesis, University of Massachusetts, Amherst, 84 pp.
This paper documents the specific impacts of channelization on songbirds, small mammals, furbearers, reptiles, and amphibians in Vermont.

Prellwitz, D. M. 1976. *Effects of Stream Channelization on Terrestrial Wildlife and Their Habitats in the Buena Vista Marsh, Wisconsin*, M. S. Thesis, University of Wisconsin, Stevens Point, Wisconsin, 113 pp.
This paper evaluates the plant and animal species composition and abundance in regards to plant successional stages from grassland to mature woods adjacent to recently dredged (6 years), old dredged (50 years), and natural streams in Wisconsin. "Bird and mammal species diversity and bird abundance increased as plant succession advanced, until a mature wooded stage was reached. Abundance of small mammals was related to the amount of ground cover and the diversity of habitats along the stream banks. Reptile and amphibian species diversity was greatest along natural and old dredged streams having partially submerged branches

and low-lying, moist areas...Waterfowl use, bird nesting, and reptile and amphibian abundance also were greatest on the undrained area"

Impacts of Stream Channel Modification on Vegetation

Anderson, B. W. and R. D. Ohmart. 1985. "Riparian revegetation as a mitigating process in streams and river restoration." In: *The Restoration of Rivers and Streams*, edited by J. A. Gore, Butterworth Publishers, Stoneham, Massachusetts, pp. 41-80.
This chapter summarizes the results of field studies of riparian habitats on the lower Colorado River (Arizona) in which efforts were made to develop plant community designs, based on field-collected data, that would house as many vertebrate species, particularly birds and rodents, as possible and support high densities of wildlife. Costs of revegetation are also presented.

Arner, D. H., H. R. Robinette, J. E. Frasier, and M. Gray. 1975. Effects of channel modification on the Luxapalila River." *Symposium on Stream Channel Modification Proceedings*, August 15-17, Harrisonburg, Virginia, 77-96.
Discusses biological data (turbidity, plankton, macroinvertebrates, fish, and furbearers) collected from an old channelized section, an unchannelized section, and a newly channelized section of the Luxapalila River in Mississippi.

Arner, D. H., H. R. Robinette, J. E. Frasier, and M. H. Gray. 1976. *Effects of Channelization of the Luxapalila River on Fish, Aquatic Invertebrates, Water, Quality, and Furbearers*, U. S. Fish and Wildlife Service, Office of Biological Services, FWS/OBS-76-08, 58 pp.
This paper presents data from an old channelized section (over 52 years), unchannelized section, and newly channelized section of a river in Mississippi and Alabama. Diversity of plankton, macroinvertebrates, and fish; average number/sample of fish and macroinvertebrates; and average weight of largemouth bass were all greater in the unchannelized section. The "productivity of the old channelized segment has not recovered to the levels exhibited in the unchannelized segment."

Baker, M., Jr., Inc. 1975. *Evaluation of the Environmental Impact to Appalachian Pennsylvania Waters of the 1972 Flood and Subsequent Stream Channelization with Future Policy Recommendations,* Report ARC-73-185-2562, PB 245 659, Prepared for Pennsylvania Fish Commission and Department of Environmental Resources, Harrisburg, Pennsylvania, 304 pp.
This extensive report evaluates the impacts of stream channelization on aquatic organisms in Pennsylvania. No long term effects were determined for the aufwuch communities and benthic invertebrates. Stream alteration is most detrimental to gamefish populations with varied recovery success.

Barclay, John S. 1980. *Impact of Stream Alterations on Riparian Communities in Southcentral Oklahoma,* U. S. Fish and Wildlife Service, Biological Services Program, FWS/OBS-80/17, 91 pp.

This report details the impacts of stream alteration in the grasslands of Oklahoma.

"Conclusions and recommendations are given on the effects of stream alteration to riparian vegetation and associated bird, mammal, amphibian, and reptile populations."

Bazemore, D. E., C. R. Hupp, and T. H. Diehl. 1991. "Wetland sedimentation and vegetation patterns near selected highway crossings in West Tennessee." ***US Geological Survey, Water-Resources Investigations Report 91-4106,*** **46 pp.**
This paper evaluates the sedimentation rates and vegetation patterns near highway crossings in West Tennessee. The sedimentation rates were highly variable without significant difference between upstream and downstream of highway crossings in eight of the eleven study sites. Three sites had significantly greater sedimentation downstream. The vegetation patterns and tree growth appear most strongly related to hydroperiod, defined as the average length of time an area is covered by water each year. The estimated average depth of flood-plain inundation increased by an average of six percent and the estimated hydroperiod increased no more than one percent because of backwater from the highway crossings at the eleven sites.

Bradt, P. T. and G. E. Wieland III. 1978. ***The Impact of Stream Reconstruction and a Gabion Installation on the Biology and Chemistry of a Trout Stream,*** **U. S. Department of the Interior, Office of Water Research and Technology, Completion Report, 62 pp.**
This report evaluates the effect of a gabion installation and stream reconstruction in a rechanneled stream in Pennsylvania. In the rechanneled section, the algae populations; benthic diversity index, biomass, total numbers, and number of taxa; conductivity; dissolved oxygen; percent oxygen saturation; alkalinity; channel depth; and flow velocity increased significantly. Orthophosphate decreased significantly.

Brooker, M. P. 1985. "The ecological effects of channelization." ***The Geographical Journal,*** **151, 63-69.**
This paper identifies the impacts which channelization in the UK has upon fish, macroinvertebrates, aquatic and bankside vegetation, birds, and mammals. Management conclusions are also presented.

Brookes, A. 1986. "Response of aquatic vegetation to sedimentation from river channelization works in England and Wales." ***Biological Conservation,*** **38, 351-367.**
This article identifies two plant responses to sedimentation: adjustment of root levels or smothering. Recommendations to minimize the impacts on plants are also given.

Brookes, A. 1987. "Recovery and adjustment of aquatic vegetation within channelization works in England and Wales." ***Journal of Environmental Management,*** **24, 365-382.**
This paper assesses the short-term recovery of vegetation following channelization in England. Long-term (24 years after channelization) impacts are also discussed.

Recommendations for minimizing the channelization impacts on aquatic vegetation are also presented.

Burns, J. W. 1972. "Some effects of logging and associated road construction on Northern California streams." *Transactions of the American Fisheries Society*, 101, 1-17.
Logging and road construction impacts of California streams are presented. "Extensive use of bulldozers in stream channels during debris removal caused excessive streambed sedimentation in narrow streams." Thinning the riparian canopy of streams can increase in the water temperature. In cold, shaded streams this can lead to an increase the production of algae, bacteria, and insects upon which fish feed. However, too much shade removal can also be detrimental to aquatic organisms.

Carothers, S. W. and R. R. Johnson. 1975. "The effects of stream channel modification on birds in the southwestern United States." *Symposium on Stream Channel Modification Proceedings*, August 15-17, Harrisonburg, Virginia, 60-76.
The effects of channelization and phreatophyte control in riparian habitats is evaluated. Discusses dependency of avian species upon riparian habitat and the environmental factors which influence species diversity and population density.

Chapman, D. W. and E. Knudsen. 1980. "Channelization and livestock impacts on salmonid habitat and biomass in Western Washington." *Transactions of the American Fisheries Society*, 109, 357-363.
"Channelization significantly reduced overhead cover, sinuosity, wetted area, and woody bank cover while increasing bank grasses. Total habitat area declined in altered areas." These alterations negatively affected the larger fish species.

Cline, L. D., R. A. Short, and J. V. Ward. 1982. "The influence of highway construction on the macroinvertebrates and epilithic algae of a high mountain stream." *Hydrobiologia*, 96, 149-159.
This paper reports the response of a Rocky Mountain stream to highway construction. "The severity of the response was a function of the flow regime and the timing and duration of the impact at a given site. The hydrologic regime and high gradient of the study stream appeared to ameliorate to some extent the potentially adverse effects of short-term perturbations engendered by highway construction activities."

Consolidation Coal Company, Interstate Commerce Commission, Navajo Nation, Department of the Interior, Bureau of Indian Affairs, Department of Transportation, and Federal Railroad Administration. 1983. *Proposed Navajo Railroad Project, New Mexico*. Washington, D. C. Department of the Interior, Bureau of Indian Affairs, 2 volumes.

This document evaluates the impact of railroad construction alternatives on the San Juan River. The impacts to the surface water resources and aquatic ecology are determined to be minimal. The most significant impacts will be upon the terrestrial vegetation and wildlife since the right-of-way will destroy the vegetation and wildlife habitat. Mitigation of erosion is suggested as the emplacement of rip-rap fill material.

Dale, E. E., Jr. 1974. *Environmental Evaluation Report on Various Completed Channel Improvement Projects in Eastern Arkansas*, Final Report to the U. S. Army Corps of Engineers, Little Rock District, Little Rock, Arkansas, 44 pp.
This report evaluates the "beneficial and adverse effects that certain channel improvement projects have had on the natural or man-made environments of selected areas in Eastern Arkansas." This paper presents a time-table of seven vegetation successional stages. This describes the dominant vegetation occurring at different times (0 to 50 years) along the streams. Fish and wildlife impacts are also discussed regarding individual species.

Dawson, F. H., E. Castellano, and M. Ladle. 1978. "Concept of species succession in relation to river vegetation and management." *International Association of Theoretical and Applied Limnology*, 20, 1429-1434.
"This study of the interaction of the life cycles of two codominant species in the upper to middle reaches of a chalk stream in Southern England was undertaken in order to illustrate and discuss the concepts of succession in a case which is of considerable importance to the management of streams. This study involved not only the cover of the stream bed by plants but also included the seasonal changes in their biomass and production in relation to climatic factors."

Dodge, W. E., E. E. Possardt, R. J. Reed, and W. P. MacConnell. 1976. *Channelization Assessment, White River, Vermont: Remote Sensing, Benthos, and Wildlife*,
U. S. Fish and Wildlife Service, Office of Biological Services, FWS/OBS-76-07, 73 pp. This report evaluates the impacts of channelization on benthos and wildlife of a Vermont river. After 8 months there was no significant difference in the benthic organisms of channelized and unchannelized areas. The majority of songbirds and small mammals were captured in the unchannelized areas, which also had the greatest species diversity. "No gross differences were observed between channelized and control (non-channelized) sites for the furbearers and amphibians. The most drastic impact on wildlife occurred at channelized sites where streamside vegetation was the most extensively destroyed."

Edwards, D. 1969. "Some effects of siltation upon aquatic macrophyte vegetation in rivers." *Hydrobiologia*, 34, 29-37.
This is a literature review of the "sources that indicate ways in which silt-induced changes to some of the principal aquatic environmental factors have caused corresponding changes in the aquatic macrophyte vegetation of South African rivers." The available data suggest that there is a general decline in aquatic vegetation due to silt.

Ellis, R. W. 1976. *The Impact of Stream Alteration on Wildlife along Tributaries of the Roanoke River, Charlotte County, Virginia*, M. S. Thesis, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, 105 pp.
This is a "comparative study of three different-aged channelized streams--3, 6, and 10 years after channelization--and an unchannelized stream (in Virginia). The relative composition of the stream side vegetation, and the abundance of small mammals and larger mammals, and the composition of winter and breeding birds was determined for each study site and compared to one another to determined the influence of stream channelization upon wildlife and their habitats." This is a good reference regarding successional processes along channelized rivers.

Ferguson, H. L. 1975. *The Impact os Stream Alteration on Wildlife along Tributaries of the Roanoke River, Charlotte County, Virginia*, M. S. Thesis, Virginia Polytechnic Institute and State University, Blacksburg, VA, 114 pp.
This is a comparative study of three different-aged channelized streams (2, 5, and 9 years after channelization) in Virginia. "Species diversity of the vegetation, small mammals, and birds increased progressively from the 2 year old stream to the 9 year old stream." The most recently altered streams appeared to have unstable environments as indicated by lower and more variable species diversity and equitability values.

Headrick, M. R. 1976b. *Effects of Stream Channelization on Fish Populations in the Buena Vista Marsh, Portage County, Wisconsin*, U. S. Fish and Wildlife Service, Office of Biological Services, FWS/OBS-76/24, 38 pp.
This paper compares fish populations from 6-8 year old and 52-62 year old ditches with populations of natural streams. Channelization reduced year-round instream cover, decreased substrate stability, and increased silt accumulation and stream temperatures. The impacts regarding these changes are discussed for several fish species. "Recovery was more rapid in ditches where spoil was spread on adjacent fields and bank vegetation left in place than in ditches where loose spoil was left on the banks." Recommendations for trout management of dredged streams are given.

Hedrick, R. D. 1975. *Impact of Channelization and Associated Land Use Changes on Wildlife Habitat*, M. S. Thesis, Oklahoma State Univ., Stillwater, OK, 46 pp.
This paper details the detrimental impacts of channelization along an Oklahoma stream. The wildlife populations in the area have been negatively impacted.

Holz, D. D. 1969. *The Ecology of the Unchannelized and Channelized Missouri River, Nebraska, with Emphasis on the life History of the Flathead Catfish*, M. A. Thesis, University of Missouri, Columbia, Missouri, 118 pp.
This study researched the ecological differences of channelized and unchannelized section of the Missouri River in Nebraska. "Growth rate of the flathead catfish was faster in the channelized river than in the unchannelized river...a collapse in population structure had taken place in the channelized river but not in the unchannelized river...The standing crop of aufwuchs was lowest in the channelized

river...In the channelized Missouri the rate of flow was greater then in the unchannelized river...Turbidity was greater in the channelized section...The chemical properties were similar."

Hupp, C. R. 1986. "Determination of bank widening and accretion rates and vegetation recovery along modified West Tennessee streams." ***Proceedings of the International Symposium on Ecological Aspects of Tree-Ring Analysis*****, August 17-21, Marymount College, Tarrytown, New York, 224-233.**
This article describes the riparian vegetation responses to channel modification in West Tennessee streams.

King, D. L. and R. C. Bell. 1964. "Influence of highway construction on a stream." ***Research Report 19, Michigan State University, Agricultural Experiment Station, East Lansing*****, 4 pp.**
This is an evaluation of destruction of natural stream environment by channel realignment. Effects on the aufwuchs (basic producers), invertebrates, fish, and stream energetics are discussed.

King, L. R. and K. D. Carlander. 1976. ***A Study of the Effects of Stream Channelization and Bank Stabilization on Warmwater Sport Fish in Iowa: Subproject No. 3. Some Effects of Short-Reach Channelization on Fishes and Fish Food Organism in Central Iowa Warm Water Streams*****, U. S. Fish and Wildlife Service, Biological Services Program, FWS/OBS-76/13, 217 pp.**
This reports the results of a study conducted "to determine whether fish and fish food organisms were affected by short-reach channelization associated with bridge replacement in the last 15 years" in Iowa. This study analyses different successional stages of channelized streams--2 and 10 to 15 years after channelization--and unchannelized streams. "The most evident impact of short-reach channelization is the removal of cover in the altered area and the loss of stream length."

Larson, L. L. and S. L. Larson. 1996. "Riparian shade and stream temperature: a perspective." ***Rangelands*****, 18(4), 149-152.**
This article discusses riparian shade as a means to prevent heating of streams. The changes in water temperature can alter the species composition of streams. "Streamside vegetation can improve bank stability, increase habitat for some species of wildlife, and serve as a component in the system as a whole but shade does not control stream temperature."

Lollis, J. P. 1981. ***The Effects on Stream Channelization on Wildlife Habitat in Eastern North Carolina*****, M. S. Thesis, North Carolina State University, Raleigh, North Carolina, 144 pp.**
This paper is an extensive examination of the impacts of channelization on wildlife habitat in North Carolina. Five different habitat condition classes and 217 species of wildlife were identified and studied. "While some species had very strong

preferences for either upland or wetland habitats, there were numerous species which were limited more by cover conditions than by the type of water regime. These species inhabited both channelized and natural stream basins if the appropriate cover was found."

Maki, T. E., A. J. Weber, D. W. Hazel, S. C. Hunter, B. T. Hyberg, D. M. Flinchum, J. P. Lollis, J. B. Rognstad, and J. D. Gregory. 1980. *Effects of Stream Channelization on Bottomland and Swamp Forest Ecosystems*, Water Resources Research Institute (WRRI) of the University of North Carolina, Report No. 147, 135 pp.
This report examines the effects of channelization on the bottomland-swamp forests of Eastern North Carolina. Only the vegetation response is considered.

Marzolf, G. R. 1978. *The Potential Effects of Clearing and Snagging on Stream Ecosystems*, U. S. Fish and Wildlife Service, Biological Services Program, FWS/OBS-78/14, 31 pp.
This report "identifies some potential ecological impacts of clearing and snagging, but does not yield quantitative predictions of the impacts." The effects of clearing and snagging on primary producers, decomposition, organic matter processing, macroinvertebrates, and fish are discussed.

McCall, J. S. and R. F. Knox. 1978. *Riparian Habitat in Channelization Projects*, U. S. Forest Service, General Technical Report No. GTR-WO-12, 125-128.
This paper reviews the techniques being used in Indiana to protect riparian vegetation and reduce the impacts on water quality, fish and wildlife habitat, and visual quality of streams caused by watershed projects.

Morris, L. A., R. N. Langemeier, T. R. Russell, and A. Witt, Jr. 1968. "Effects of main stem impoundments and channelization upon the limnology of the Missouri River, Nebraska." *Transactions of the American Fisheries Society*, 97(4), 380-388.
This paper examines the impacts of impoundment and channelization of a Nebraska river. "Channelization of the river has reduced both the size and variety of aquatic habitat by destroying key productive areas." The significant change in the benthic standing crop of drift was attributed to the channelization.

Murphy, M. L., C. P. Hawkins, and N. H. Anderson. 1981. "Effects of canopy modification and accumulated sediment pollution on stream communities associated with clear-cut logging in the Western Cascade Range of Oregon." *Transactions of the American Fisheries Society*, 110, 469-478.
The impacts of canopy modification and increased sediments on a stream in Oregon are presented. "Streams traversing open clear-cuts had greater rates of microbial respiration, and greater densities or biomasses of aufwuchs, benthos, drift, salamanders, and trout than did the shaded, forested sites regardless of sediment composition. It is concluded that for these small Cascade Range streams, changes in trophic status and increased primary productivity resulting from shade removal may mask or override effects of sedimentation."

Pilli, A., D. O. Carle, E. Kline, Q. Pickering, and J. Lazorchak. 1988. "Effects of pollution on freshwater organisms." *Journal of the Water Pollution Control Federation*, 60(6), 994-1065.
This is a very extensive literature review of the impacts of pollutants (toxic chemicals, effluents, leachates, oils, and pH effects) on freshwater organisms (fish, invertebrates, and algae.)

Prellwitz, D. M. 1976. *Effects of Stream Channelization on Terrestrial Wildlife and Their Habitats in the Buena Vista Marsh, Wisconsin*, M. S. Thesis, University of Wisconsin, Stevens Point, Wisconsin, 113 pp.
This paper evaluates the plant and animal species composition and abundance in regards to plant successional stages from grassland to mature woods adjacent to recently dredged (6 years), old dredged (50 years), and natural streams in Wisconsin. "Bird and mammal species diversity and bird abundance increased as plant succession advanced, until a mature wooded stage was reached. Abundance of small mammals was related to the amount of ground cover and the diversity of habitats along the stream banks. Reptile and amphibian species diversity was greatest along natural and old dredged streams having partially submerged branches and low-lying, moist areas...Waterfowl use, bird nesting, and reptile and amphibian abundance also were greatest on the undrained area"

Raven, P. J. 1986. "Changes of in-channel vegetation following two-stage channel construction on a small rural clay river." *Journal of Applied Ecology*, 23, 333-345.
This paper reports of the vegetation changes in the River Roding in England after two-stage channel construction. The study concludes that "two-stage channel construction is ecologically preferable to channelization but appropriate measures to counter excessive vegetation growth must be incorporated if the short-term benefits are to be maintained in the longer term."

Samsel, G. L., Jr. 1973. "Effects of sedimentation on the algal flora of a small recreational impoundment." *Water Resources Bulletin*, 9(6), 1145-1152.
The effects of sedimentation upon algal composition, primary productivity rates, and chemical nutrient concentrations were investigated in a Virginia impoundment. Sediments derived from lake front home construction decreased the algal genera from 24 to 16, decreased productivity two fold, and significantly increased several important nutrients.

United States Coast Guard, Eighth District. 1976. *Greater New Orleans Mississippi River Bridge No. 2, Orleans Parish-Jefferson Parish, Louisiana, Draft Environmental Impact Statement.*
This document proposes that the impact to the ecology due to bridge construction will be minimal. The bridge approach area will require the removal of vegetation and the noise may temporarily disrupt the normal activities of the limited wildlife

populations. Since the Mississippi River already has high levels of sediment and turbidity, the fish should not be severely impacted.

Vandre, W. G. 1975. *Effects of Channel Redredging on Wildlife and Wildlife Habitat of Buena Vista Marsh*, M. S. Thesis, University of Wisconsin, Stevens Point, 87 pp.
This paper examines the impacts of channel redredging on wildlife and their habitat in Wisconsin. Vegetation, waterfowl, non-game birds, and mammals are evaluated for impacts. Vegetation diversity was limited on recently channelized banks. Appropriate areas for waterfowl breeding were also reduced by channelization. The non-game bird and mammal species found along the ditch banks were associated with the diversity of vegetative cover.

Vogler, J. P. 1978. *Effects of Grazing, Clearing, and Stream Channelization on Riparian and Associated Vegetation of Guthrie County, Iowa*, M. S. Thesis, Iowa State University, Ames, Iowa, 79 pp.
This paper describes the successional stages of vegetation following channelization in Iowa. Long and short-term vegetation changes are discussed.

Wharton, C. H. 1971. "Channelization impairs or destroys the terrestrial and aquatic wildlife resource base." *Proceedings on Stream Channelization*, pages 2189-2201, U. S. Congress, House of Representatives, Part IV, U. S. Government Printing Office, Washington, D. C., 3711 pp.
This paper discusses the detrimental impacts of channelization upon wildlife(fish, birds, plants, and invertebrates) in the Southeastern United States.

Mitigation and/or Remediation Measures for Vegetation Impacts

Anderson, B. W. and R. D. Ohmart. 1979. "Riparian revegetation: an approach to mitigating for a disappearing habitat in the Southwest." *The Mitigation Symposium: A National Workshop on Mitigating Loss of Fish and Wildlife Habitats*, July 16-20, Colorado State University, Fort Collins, Colorado, Rocky Mountain Forest and Range Experiment Station General Technical Report RM-65, 481-487.
This paper describes a revegetation project on the lower Colorado River to mitigate riparian habitat losses. While the costs of revegetation were high, the wildlife use values were higher than predicted.

Beeson, C. E. and P. F. Doyle. 1995. "Comparison of bank erosion at vegetated and non-vegetated channel bends." *Water Resources Bulletin*, 31(6), 983-990.
This article details the importance of riparian vegetation to help reduce erosion. After a major flood event in British Columbia, it was determined that "bends without riparian vegetation were found to be nearly five times as likely as vegetated bends to have undergone detectable erosion...Major bank erosion was 30 times more prevalent on non-vegetated bends as on vegetated bends."

Brookes, A. 1986. "Response of aquatic vegetation to sedimentation from river channelization works in England and Wales." ***Biological Conservation*****, 38, 351-367.**
This article identifies two plant responses to sedimentation: adjustment of root levels or smothering. Recommendations to minimize the impacts on plants are also given.

Brookes, A. 1987. "Recovery and adjustment of aquatic vegetation within channelization works in England and Wales." ***Journal of Environmental Management*****, 24, 365-382.**
This paper assesses the short-term recovery of vegetation following channelization in England. Long-term (24 years after channelization) impacts are also discussed. Recommendations for minimizing the channelization impacts on aquatic vegetation are also presented.

Bulkley, R. V., R. W. Bachmann, K. D. Carlander, H. L. Fierstine, L. R. King, B. W. Menzel, S. L. Witten, and D. W. Zimmer. 1976. ***Warmwater Stream Alteration in Iowa: Extent, Effects on Habitat, Fish, and Fish Food, and Evaluation of Stream Improvement Structures (Summary Report)*****, U. S. Fish and Wildlife Service, Biological Services Program, FWS/OBS-76/16, 39 pp.**
"This report summarizes the results given in 5 other subproject reports" regarding stream alteration in Iowa. The "differences in populations of fish and fish-food organisms in channelized and unchannelized streams, effects of stream alterations for highway bridge construction, and the value of stream-bank stabilization structures to fish habitat" are the topics covered.

Hodder, R. L. 1970. ***Revegetation Methods and Criteria for Bare Areas Following Highway Construction*****. Montana State Highway Commission, U. S. Department of Transportation, Federal Highway Administration, 97 pp.**
This study investigates the seeding and mulching of roadsides following construction in Montana. Recommendations for effective revegetation are presented.

Hottenstein, W. L. 1952. "Adaptation of certain herbaceous material for highway slope control." ***Reports, Including Special Papers*****, U. S. National Research Council, Highway Research Board, 36-45.**
This paper presents the investigation of the effectiveness of various grasses and crown vetch as slope erosion-control vegetation in Pennsylvania. Crown vetch was probably the best overall ground cover under the given conditions.

Hupp, C. R. and A. Simon. 1991. "Bank accretion and the development of vegetated depositional surfaces along modified alluvial channels." ***Geomorphology*****, 4, 111-124.**
This paper describes the recovery of stable bank form and development of vegetated depositional surfaces along the banks of channelized West Tennessee streams. "Bank accretion and vegetative regrowth appear to be the most important environmental processes involved in channel bank recovery from channelization or rejuvenation."

Knox, R. F and J. D. McCall. 1979. "Habitat mitigation in Indiana's authorized channelization projects." ***The Mitigation Symposium: A National Workshop on Mitigating Loss of Fish and Wildlife Habitats*****, July 16-20, Colorado State University, Fort Collins, Colorado, Rocky Mountain Forest and Range Experiment Station General Technical Report RM-65, 582-585.**
This article describes the techniques being used in Indiana to protect riparian vegetation, and fish and wildlife habitat. The techniques include sediment traps, one-sided construction, low-impact debris removal, pool-riffle construction in bedrock, revegetation, shade maintenance, installation of fish pools with deflectors and constructed riffles in earth structures, fencing and vegetation markers, and wetland acquisition.

Kochman, E. 1979. "Channelization in Colorado--past, present, and future." ***The Mitigation Symposium: A National Workshop on Mitigating Loss of Fish and Wildlife Habitats*****, July 16-20, Colorado State University, Fort Collins, Colorado, Rocky Mountain Forest and Range Experiment Station General Technical Report RM-65, 586-589.**
This article describes the Stream Protection Act of colorado and its impacts on stream alteration projects. A stream relocation project is provided as an example of mitigating the impacts on the riparian ecosystem. Revegetation and aquatic habitat improvements were successful in this project.

Lewis, G. 1984. ***Rivers and Wildlife Handbook--A Guide to Practices which Further the Conservation of Wildlife on Rivers*****, edited by G. Williams, Royal Society for the Protection of Birds, Publications Department, Lincoln, England, 295 pp.**
This handbook "describes works on rivers--mainly in England and Wales--which have successfully integrated the conservation of wildlife habitat with land drainage and flood alleviation schemes."

Nunnally, N. R. 1978. "Improving channel efficiency without sacrificing fish and wildlife habitat: the case for stream restoration." ***Strategies for Protection and Management of Floodplain Wetlands and Other Riparian Ecosystems Symposium Proceedings*****, December 11-13, Callaway Gardens, Georgia, 394-399.**
This article describes an economically and environmentally satisfying solution to conventional channelization, which is stream restoration. This "creates a more stable channel by removing debris, providing fairly uniform cross sections, and stabilizing stream banks with minimal disturbance of the streambed and riparian vegetation."

Ree, W. O. 1960. "The establishment of vegetation lined waterways." ***Short Course on Roadside Development*****, Department of Architecture and Landscape Architecture, Columbus, Ohio, 54-65.**
This article describes the effectiveness of vegetation as a liner in newly graded waterways.

Riethman, D. T. 1992. "Impact of environmental features on completed channel modifications." Paper presentation at the International Winter Meeting of the American Society of Agricultural Engineers, Paper No. 92-2644, 12 pp.
This paper details the Little Auglaize River Watershed Project in Ohio. The project implemented construction methods and installed environmental features to mitigate the losses of fish and wildlife habitat. These features have had a positive impact on the environment and still provide the needed flood control.

Shields, F. D., Jr., A. J. Bowie, and C. M. Cooper. 1995. "Control of streambank erosion due to bed degradation with vegetation and structure." *Water Resources Bulletin*, 31(3), 475-489.
This article evaluates the effectiveness of vegetation and structures to control erosion in Mississippi rivers. Revegetation may not be necessary in all cases.

Impacts of Stream Channel Modification on Chemical Properties

Bradt, P. T. and G. E. Wieland III. 1978. *The Impact of Stream Reconstruction and a Gabion Installation on the Biology and Chemistry of a Trout Stream*, U. S. Department of the Interior, Office of Water Research and Technology, Completion Report, 62 pp.
This report evaluates the effect of a gabion installation and stream reconstruction in a rechanneled stream in Pennsylvania. In the rechanneled section, the algae populations; benthic diversity index, biomass, total numbers, and number of taxa; conductivity; dissolved oxygen; percent oxygen saturation; alkalinity; channel depth; and flow velocity increased significantly. Orthophosphate decreased significantly.

Hathaway, C. B., Jr. 1978. *Stream Channel Modification in Hawaii, Part C: Tolerance of Native Stream Species to Observed Levels of Environmental Variability*. FWS/OBS-78/18. USFWS National Stream Alteration Team, Columbia, Missouri. 59 pp.
This booklet describes the increases in physicochemical variations (conductivity, pH, and dissolved oxygen) correlated to channel modification of Hawaiian streams. These variations were determined to reduce the abundance of several endemic gobiid fishes in the altered streams.

Holz, D. D. 1969. *The Ecology of the Unchannelized and Channelized Missouri River, Nebraska, with Emphasis on the life History of the Flathead Catfish*, M. A. Thesis, University of Missouri, Columbia, Missouri, 118 pp.
This study researched the ecological differences of channelized and unchannelized section of the Missouri River in Nebraska. "Growth rate of the flathead catfish was faster in the channelized river than in the unchannelized river...a collapse in population structure had taken place in the channelized river but not in the unchannelized river...The standing crop of aufwuchs was lowest in the channelized river...In the channelized Missouri the rate of flow was greater then in the unchannelized river...Turbidity was greater in the channelized section...The chemical properties were similar."

Huish, M. T. and G. B. Pardue. 1978. *Ecological Studies of One Channelized and Two Unchannelized Wooded Coastal Swamp Streams in North Carolina*, U. S. Fish and Wildlife Service, Office of Biological Services, FWS/OBS-78/85, 72 pp.
This report presents the differences in the chemical, physical, and biological components of three small cypress-gum wooded swamp streams in North Carolina. "Several differences between the channelized and unchannelized systems were noted."

Langemeier, R. M. 1965. *Effects of Channelization on the Limnology of the Missouri River, Nebraska, with Emphasis on Food Habits and Growth of the Flathead Catfish*, M. A. Thesis, University of Missouri, Columbia, MO, 156 pp.
This paper evaluates the limnological differences in channelized and unchannelized portions of the Missouri River. The chemical properties were similar. The growth rates of the flathead catfish was slower in the unchannelized section. Invertebrate drift was a good index for catfish growth. "The difference in the abundance of aufwuchs and the difference in the degree of aggregation of these organisms is assumed to be the reason for the difference in size of young-of-the-year flathead catfish between the two stations.

Ogbeibu, A. E. and R. Victor. 1989. "The effects of road and bridge construction on the bank-root macrobenthic invertebrates of a Southern Nigerian stream." *Environmental Pollution*, 56, 85-100.
This article presents the results of a comparative study on a fourth order Nigerian stream to evaluate the effects of a road and bridge construction on the macrobenthic invertebrates of the bank-root biotope. "Siltation and sedimentation appear to be the important factors affecting macroinvertebrates." Construction did not affect the chemical characteristics of the stream.

Samsel, G. L., Jr. 1973. "Effects of sedimentation on the algal flora of a small recreational impoundment." *Water Resources Bulletin*, 9(6), 1145-1152.
The effects of sedimentation upon algal composition, primary productivity rates, and chemical nutrient concentrations were investigated in a Virginia impoundment. Sediments derived from lake front home construction decreased the algal genera from 24 to 16, decreased productivity two fold, and significantly increased several important nutrients.

Schmal, R. N. and D. F. Sanders. 1978. *Effects of Stream Channelization on Aquatic Macroinvertebrates, Buena Vista Marsh, Portage County, Wisconsin*, U.S. Fish and Wildlife Service, Biological Services Program, FWS/OBS-78/92, 80 pp.
This report assesses the "effects of channelization on density and biomass of benthic and drifting macroinvertebrates, amount of drifting seston, and water temperature and chemistry in Wisconsin...Substrate strongly influenced macroinvertebrate populations...Channelization affected macroinvertebrate populations by creating unstable substrate conditions...Channelization appeared to affect invertebrate drift through its influence on drifting seston and benthos...Water temperature and chemistry did not differ greatly among the natural streams and ditches..."

Simpson, P. W., J. R. Newman, M. A. Keirn, R. M. Matter, and P. A. Guthrie. 1982. *Manual of Stream Channelization Impacts on Fish and Wildlife*, U. S. Fish and Wildlife Service, Biological Services Program, FWS/OBS-82/24, 155 pp.
This is an extensive compilation of the impacts of stream channelization on wildlife. The "major topics (of this report) include: 1) regulatory history of stream channelization; 2) structural, physical, and chemical impacts of channelization; and 3) biological impacts of channelization."

Swedberg, S. E. and Nevala. 1965. "Evaluation of fish habitat destruction in Little prickly Pear Creek due to construction of Interstate Highway 15." Montana Fish and Game Department, *Job Completion Report, F-5-R-14*, 11 pp.
This paper presents the data for temperature, water quality and quantity, bottom fauna, and fish for the creek in graphs and tables. This is a preliminary investigation that does not provide any conclusions and the only recommendation is to continue the study.

Taylor, B. R. and J. C. Roff. 1986. "Long-term effects of highway construction on the ecology of a Southern Ontario stream." *Environmental Pollution*, 40, 317-344.
This paper evaluates the long-term (6 years) impacts of highway construction on the chemical, physical, and biological parameters within a Southern Ontario stream

Impacts of Stream Channel Modification on Physical Properties

Bradt, P. T. and G. E. Wieland III. 1978. *The Impact of Stream Reconstruction and a Gabion Installation on the Biology and Chemistry of a Trout Stream*, U. S. Department of the Interior, Office of Water Research and Technology, Completion Report, 62 pp.
This report evaluates the effect of a gabion installation and stream reconstruction in a rechanneled stream in Pennsylvania. In the rechanneled section, the algae populations; benthic diversity index, biomass, total numbers, and number of taxa; conductivity; dissolved oxygen; percent oxygen saturation; alkalinity; channel depth; and flow velocity increased significantly. Orthophosphate decreased significantly.

Hansen, D. R. and R. J. Muncy. 1971. "Effects of stream channelization on fishes and bottom fauna in the Little Sioux River, Iowa." Completion Report of Project No. A-035-IA, Iowa State Water Resources Research Institute, 118 pp.
This paper reports the findings of a study which evaluated the differences in certain physical factors, bottom fauna, and fish populations in channelized and unchannelized portions of the Little Sioux River, Iowa, occurring in 1969-71.

Headrick, M. R. 1976b. *Effects of Stream Channelization on Fish Populations in the Buena Vista Marsh, Portage County, Wisconsin*, U. S. Fish and Wildlife Service, Office of Biological Services, FWS/OBS-76/24, 38 pp.

This paper compares fish populations from 6-8 year old and 52-62 year old ditches with populations of natural streams. Channelization reduced year-round instream cover, decreased substrate stability, and increased silt accumulation and stream temperatures. The impacts regarding these changes are discussed for several fish species. "Recovery was more rapid in ditches where spoil was spread on adjacent fields and bank vegetation left in place than in ditches where loose spoil was left on the banks." Recommendations for trout management of dredged streams are given.

Holz, D. D. 1969. *The Ecology of the Unchannelized and Channelized Missouri River, Nebraska, with Emphasis on the life History of the Flathead Catfish*, M. A. Thesis, University of Missouri, Columbia, Missouri, 118 pp.
This study researched the ecological differences of channelized and unchannelized section of the Missouri River in Nebraska. "Growth rate of the flathead catfish was faster in the channelized river than in the unchannelized river...a collapse in population structure had taken place in the channelized river but not in the unchannelized river...The standing crop of aufwuchs was lowest in the channelized river...In the channelized Missouri the rate of flow was greater then in the unchannelized river...Turbidity was greater in the channelized section...The chemical properties were similar."

Huish, M. T. and G. B. Pardue. 1978. *Ecological Studies of One Channelized and Two Unchannelized Wooded Coastal Swamp Streams in North Carolina*, U. S. Fish and Wildlife Service, Office of Biological Services, FWS/OBS-78/85, 72 pp.
This report presents the differences in the chemical, physical, and biological components of three small cypress-gum wooded swamp streams in North Carolina. "Several differences between the channelized and unchannelized systems were noted."

Hupp, C. R. and D. E. Bazemore. 1993. "Temporal and spatial patterns of wetland sedimentation, West Tennessee." *Journal of Hydrology*, 141, 179-196.
This paper presents the dendrogeomorphic analyses of temporal and spatial variation in sedimentation rates in the vicinity of two selected causeway-bridge crossing in forested West Tennessee wetlands. "Temporal sedimentation rates may be associated with timing of channelization and recovery, and agricultural intensity. Deposition rates were inversely correlated with elevation and degree of ponding. Downstream deposition of sand splays appears to be related to flow constriction and may be extensive. No clear differences in upstream and downstream sedimentation patterns that may be associated with bridge structures were documented. Increased velocity and turbulence at flow constrictions may account for substantial overbank sand deposition."

Larson, L. L. and S. L. Larson. 1996. "Riparian shade and stream temperature: a perspective." *Rangelands*, 18(4), 149-152.
This article discusses riparian shade as a means to prevent heating of streams. The changes in water temperature can alter the species composition of streams. "Streamside vegetation can improve bank stability, increase habitat for some species

of wildlife, and serve as a component in the system as a whole but shade does not control stream temperature."

Luedtke, R. J., F. J. Watts, M. A. Brusven, and T. E. Roberts. 1973. "Physical and biological rehabilitation of a stream." ***Hydraulic Engineering and the Environment*****, Proceedings of the Twenty-first Annual Hydraulics Division Specialty Conference, Montana State University, Bozeman, August 15-17, 1-10.**
This study conducted inventories of problem reaches in a silted stream, evaluated the effectiveness of log drop structures and gabion constrictors, and examined the seasonal transport of sediments in different reaches.

McCall, J. S. and R. F. Knox. 1978. ***Riparian Habitat in Channelization Projects*****, U. S. Forest Service, General Technical Report No. GTR-WO-12, 125-128.**
This paper reviews the techniques being used in Indiana to protect riparian vegetation and reduce the impacts on water quality, fish and wildlife habitat, and visual quality of streams caused by watershed projects.

Murphy, M. L., C. P. Hawkins, and N. H. Anderson. 1981. "Effects of canopy modification and accumulated sediment pollution on stream communities associated with clear-cut logging in the Western Cascade Range of Oregon." ***Transactions of the American Fisheries Society*****, 110, 469-478.**
The impacts of canopy modification and increased sediments on a stream in Oregon are presented. "Streams traversing open clear-cuts had greater rates of microbial respiration, and greater densities or biomasses of aufwuchs, benthos, drift, salamanders, and trout than did the shaded, forested sites regardless of sediment composition. It is concluded that for these small Cascade Range streams, changes in trophic status and increased primary productivity resulting from shade removal may mask or override effects of sedimentation."

Reed, J. R. 1977. "Stream community response to road construction sediments." ***Virginia Water Resources Research Center Bulletin 97*****, 61 pp.**
"This publication summarizes a two-year study in the effectiveness of erosion-control measures, the effect of silt on macrobenthic and fish populations, and the ability of these populations to recover from stream degradation."

Reed, L. A. 1980. "Suspended-sediment discharge, in five streams near Harrisburg, Pennsylvania, before, during, and after highway construction." ***Geological Survey Water-Supply Paper 2072*****, 37 pp.**
This paper studies the effects of highway construction on suspended sediment discharge in streams. The effectiveness of offstream ponds, seeding and mulching, rock dams and bales, and onstream ponds were evaluated as erosion-control devices.

Samsel, G. L., Jr. 1973. "Effects of sedimentation on the algal flora of a small recreational impoundment." ***Water Resources Bulletin*****, 9(6), 1145-1152.**
The effects of sedimentation upon algal composition, primary productivity rates, and chemical nutrient concentrations were investigated in a Virginia impoundment.

Sediments derived from lake front home construction decreased the algal genera from 24 to 16, decreased productivity two fold, and significantly increased several important nutrients.

Schaplow, B. M. 1976. "The effects of channelization and mitigation on the morphology and trout populations of the St. Regis River Montana." M. S. Thesis, Montana State University, Bozeman, Montana, 46 pp.
This study measured trout populations and stream morphology changes to determine the impacts of highway and railroad construction activities along the St. Regis River, Montana.

Simpson, P. W., J. R. Newman, M. A. Keirn, R. M. Matter, and P. A. Guthrie. 1982. *Manual of Stream Channelization Impacts on Fish and Wildlife*, U. S. Fish and Wildlife Service, Biological Services Program, FWS/OBS-82/24, 155 pp.
This is an extensive compilation of the impacts of stream channelization on wildlife. The "major topics (of this report) include: 1) regulatory history of stream channelization; 2) structural, physical, and chemical impacts of channelization; and 3) biological impacts of channelization."

Swedberg, S. E. and Nevala. 1965. "Evaluation of fish habitat destruction in Little Prickly Pear Creek due to construction of Interstate Highway 15." Montana Fish and Game Department, *Job Completion Report, F-5-R-14*, 11 pp.
This paper presents the data for temperature, water quality and quantity, bottom fauna, and fish for the creek in graphs and tables. This is a preliminary investigation that does not provide any conclusions and the only recommendation is to continue the study.

Swerdon, P. M. and R. R. Kountz. 1973. *Sediments Runoff Control at Highway Construction Sites: A Guide for Water Quality Protection*, Engineering Research Bulletin B-108, Pennsylvania State University, University Park, Pennsylvania, 70 pp.
This report summarizes the "effects of suspended sediment on water quality, the relationship between turbidity and suspended sediment, methods of sediment analysis, and the nature of the erosion process." The detrimental effects of suspended sediments upon aquatic organisms are "mechanical abrasion, obstructive silting, reducing light penetration, providing a surface for the growth of microorganisms, absorbing or adsorbing chemical, and inhibiting normal temperature fluctuations."

Taylor, B. R. and J. C. Roff. 1986. "Long-term effects of highway construction on the ecology of a Southern Ontario stream." *Environmental Pollution*, 40, 317-344.
This paper evaluates the long-term (6 years) impacts of highway construction on the chemical, physical, and biological parameters within a Southern Ontario stream

Wolman, M. G. 1964. ***Problems Posed by Sediment Derived from Construction Activities in Maryland*, Report to the Maryland Water Pollution Control Commission, Annapolis,Maryland, 125 pp.**
This report presents problems of construction derived sediments and recommendations for reduction in Maryland. The problems appear to be local and variable in magnitude, but include reduction of channel capacity, alteration of the flora and fauna, and reduction in storage capacity of reservoirs.

Mitigation and/or Remediation Measures for Physical Impacts

***Journal of Logging Management*. 1978. "Culvert considerations which will affect future maintenance." 18-21.**
This article addresses the topics of culvert selection, placement, and maintenance.

Lickwar, P., C. Hickman, and F. W. Cubbage. 1992. "Costs of protecting water quality during harvesting on private forestlands in the Southeast." *Southern Journal of Applied Forestry*, 16, 13-20.
This paper presents the results of an economic analysis of logging management practices. "Seed, fertilizer, and mulch, broad based dips, and water bars were the most expensive practices for protecting water quality during harvesting on a total cost basis. Culvert installation, streamside management zones, and road relocation cost were less expensive."

Mih, W. C. and G. C. Bailey. 1979. "A machine for mitigation of salmonid spawning habitat from silting." *The Mitigation Symposium: A National Workshop on Mitigating Loss of Fish and Wildlife Habitats*, July 16-20, Colorado State University, Fort Collins, Colorado, Rocky Mountain Forest and Range Experiment Station General Technical Report RM-65, 645-648.
This paper describes "a machine developed to remove silt and sediments from spawning gravels." Several alternatives to reduce the detrimental effects of sediments are also presented which include reduce the source of sediments upstream, replace spawning beds with new gravel, mechanically disturb the beds to 'clean' the gravel, create a hydraulic disturbance by sluice gate action--baffle gate, and utilize a hydraulic flushing and suction system.

Reed, J. R. 1977. "Stream community response to road construction sediments." *Virginia Water Resources Research Center Bulletin* 97, 61 pp.
"This publication summarizes a two-year study in the effectiveness of erosion-control measures, the effect of silt on macrobenthic and fish populations, and the ability of these populations to recover from stream degradation."

Reed, L. A. 1976. "Sediment control during highway construction in Central Pennsylvania." *Environmental Aspects of Irrigation and Drainage; Proceedings of a Specialty Conference*, 497-507.
Detention ponds (offstream and onstream) were evaluated to determine the effectiveness of reducing sediment and turbidity in streams below construction projects in Central Pennsylvania.

Reed, L. A. 1980. "Suspended-sediment discharge, in five streams near Harrisburg, Pennsylvania, before, during, and after highway construction." *Geological Survey Water-Supply Paper 2072*, 37 pp.
This paper studies the effects of highway construction on suspended sediment discharge in streams. The effectiveness of offstream ponds, seeding and mulching, rock dams and bales, and onstream ponds were evaluated as erosion-control devices.

United States National Research Council, Highway Research Board. 1973. "Erosion control on highway construction." *National Cooperative Highway Research Program, Synthesis of Highway Practice 18*, 52 pp.
Methods of erosion control during and after highway construction are discussed.

Winger, P. V., C. M. Bishop, R. S. Gesne, and R. M. Todd, Jr. 1976. *Evaluation Study of Channelization and Mitigation Structures in Crow Creek, Franklin County, Tennessee and Jackson County, Alabama*, Report submitted to the U. S. Soil Conservation Service, 369 pp.
This is an extensive report which evaluates "the influence of instream mitigation structures on the physical and biological characteristics of the stream (Crow Creek) and to provide recommendations for future placement and design of such structures."