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16. Abstract:

As part of roadway construction, TxDOT commonly modifies or relocates stream channels. Depending on the degree and extent of modification, this practice can result in adverse impacts on aquatic and riparian habitats along the affected stream reach. Channel modifications are often undertaken without consideration of their aesthetic impact on the surrounding landscape. State and federal government agencies recognize the ecological importance of stream channel habitats and are charged with their protection. Therefore, alternatives to traditional channel modification are necessary and mitigation measures must be developed where modifications are unavoidable. The existing design guidelines (as given in the TxDOT Design Manual - Hydraulic Volume) contain many qualitative suggestions in this regard, but these need to be more vigorously enforced, more specific, and more quantitative in nature.

The first part of this document comprises a statement of guiding principles or recommendations. These recommendations are based on our review of the pertinent literature regarding these issues (report submitted previously) and field examination of selected problem areas provided by TxDOT. The second part of this document consists of a review of common problems, examples, and suggested procedures. A suggested data collection format to be considered for possible inclusion in future TxDOT Design Manuals is presented under separate cover. In addition, suggested modifications to the design manual to include the principles are presented under separate cover.

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AESTHETIC, ENVIRONMENTAL, AND GEOMORPHOLOGICAL IMPLICATIONS OF CHANNEL MODIFICATIONS

by

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Research Report Number 7-2983

conducted for

Texas Department of Transportation

by the

DEPARTMENT OF CIVIL ENGINEERING

TEXAS TECH UNIVERSITY

October 1998

IMPLEMENTATION STATEMENT

Numerous issues require resolution to implement the findings of the research conducted on this project. The recommendations presented in the Project Summary Report should be implemented, particularly those involving training of design personnel and coordination between Design Division and Environmental Division. It is imperative that the perspective of the designer be shifted from focus only on the channel/bridge site to the dynamic condition of the river being crossed or modified. Finally, TxDOT should consider selecting several river basins for long-term collection of data that can be used to test and validate design procedures as they are created and modified.

Prepared in cooperation with the Texas Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration.

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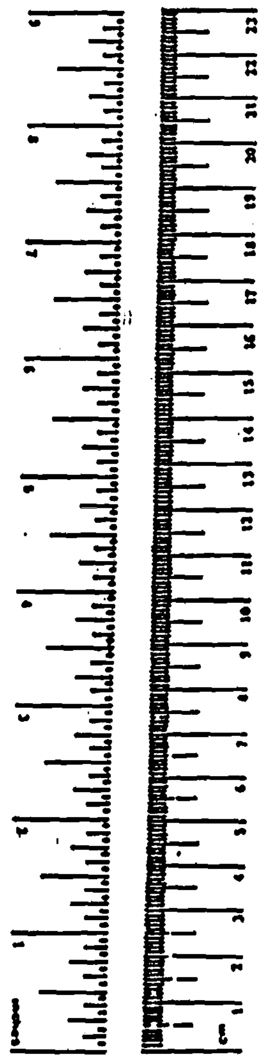
METRIC CONVERSION FACTORS

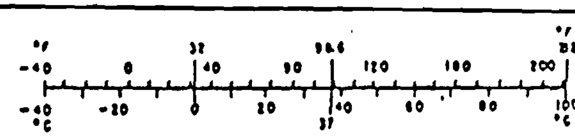
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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INTRODUCTION

As part of roadway construction, TxDOT commonly modifies or relocates stream channels. Depending on the degree and extent of modification, this practice can result in adverse impacts on aquatic and riparian habitats along the affected stream reach. Channel modifications are often undertaken without consideration of their aesthetic impact on the surrounding landscape. State and federal government agencies recognize the ecological importance of stream channel habitats and are charged with their protection. Therefore, alternatives to traditional channel modification are necessary and mitigation measures must be developed where modifications are unavoidable. The existing design guidelines (as given in the TxDOT Design Manual - Hydraulic Volume) contain many qualitative suggestions in this regard, but these need to be more vigorously enforced, more specific, and more quantitative in nature.

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PART I - GUIDING PRINCIPLES

RECOMMENDATION 1 - THE NEED FOR APPROPRIATE DEFINITION

It is necessary and important to distinguish between *structural*, *aesthetic*, and *environmental* issues associated with stream channel crossings and modifications. Such a distinction is necessary for TxDOT personnel, appropriate regulatory agencies, and also for the general motoring public. *Structural* issues involve the stability, performance, and safety of the roadway, abutments and support structures as well as associated grade control, bank erosion control, and channel modifications. *Aesthetic* issues involve the visual appearance of these structures as part of the surrounding landscape. *Environmental* issues involve the impact of these structures on aquatic and riparian plant and animal species in the affected reach of the stream channel.

It is important to distinguish between these three areas of concern because confusion arises when they are not separated. For example, spray-painted graffiti on the abutments of channel crossings comprises an aesthetic issue. For the most part, graffiti has little or no structural or environmental impact. It is unsightly; however, materials or design methods to minimize graffiti or methods employed for its removal constitute an aesthetic concern, not an environmental one. In contrast, endangerment of bridge abutments by natural channel migration is a common structural stability problem, but is not an aesthetic or environmental issue. Natural channel migration results in erosion and bank failure regardless of whether or not a channel crossing is present.

Similarly, it is important to distinguish between impacts resulting from *natural* processes that effect a stream channel and *artificial* or "man-made" effects that result from the installation of structures in and adjacent to a stream channel. For example, in its natural unconstrained state, a freely meandering stream channel will undermine its banks and change its position over time, and sediment will accumulate or be eroded from the bed and banks of the channel. Aesthetic or environmental concerns that result from the natural behavior of a stream channel, such as lateral channel migration or sediment aggradation, is not the responsibility of TxDOT. Therefore, TxDOT should not be charged with the mitigation or remediation of these problems unless these processes affect the structural stability, maintenance, or safety of a structure. Such natural channel changes may have nothing to do with the presence of the structure, and any aesthetic or environmental concerns that arise from them must be dealt with in that context.

Lastly, installation of channel crossings and associated modifications may result in both *positive* and *negative* impacts on structural, aesthetic, and environmental conditions. A *positive* impact is one that either does not affect or tends to enhance the structural stability, aesthetic qualities, or habitat in the vicinity of the modification. A *negative* impact is one that tends to adversely affect the structural stability, aesthetic qualities, or habitat in the vicinity of the modification. If an effort is required to minimize adverse or "negative" impacts brought about by channel modifications, it is important to define what a "negative" impact is. A negative structural impact (for example, sediment aggradation or growth of in-channel vegetation) may reduce the hydraulic efficiency of a structure, but may also enhance local environmental conditions (creation of low flow stage pools and riparian habitat). In the opinion of some, such a change may also result in a negative aesthetic impact (for example, reduced visibility and mosquito infestation). In contrast, some negative environmental impacts that alter the stream channel habitat around a structure may have no impact on structural or aesthetic properties. Positive and negative impacts may reinforce each other or act in opposition. For example, installation of grade control structures, such as check dams, may be effective in minimizing channel downcutting (a "positive" structural impact), but may also prevent upstream species migration (a "negative" environmental impact). Use of some materials for bank erosion control (a "positive" structural impact) may foster colonization by some species (a "positive" environmental impact) but limit or exclude others (a "negative" environmental impact). Therefore, a means of comparing and weighing alternative design and mitigation methods must be developed to balance economic, social, and environmental perspectives. Generally speaking, if sound hydraulic design features are incorporated in stream channel modifications that offer "least resistance" to natural channel behavior, thus preserving the natural system with minimum impact, aesthetic and environmental concerns will be much less severe.

RECOMMENDATION 2 - AN EMPHASIS ON DYNAMIC PROPERTIES

Environmentally sensitive design and mitigation procedures should emphasize the fact that the entire stream channel system and surrounding floodplain is *dynamic* and changing over time. Change occurs in response to both natural "geological" and "biological" processes, as well as human activity. Such an understanding is necessary for in-house TxDOT design engineers in order to promote a view of designing with nature, rather than approaches that require limiting or training the channel (which can be very expensive to maintain). It is also necessary for regulatory agencies and the general motoring public to understand that many of the visible changes they observe at channel crossings are natural, and not a response to the presence of the structure itself.

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. Furthermore, there is a time lag between the onset and resulting impacts of morphologic change, and a complex feedback between processes effecting change, so there is often a long response time required for the full effects to be felt. There are 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* (Figure 1). 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 well documented in many case histories of natural stream channels and has been replicated in laboratory flume experiments, as well as modeled 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.

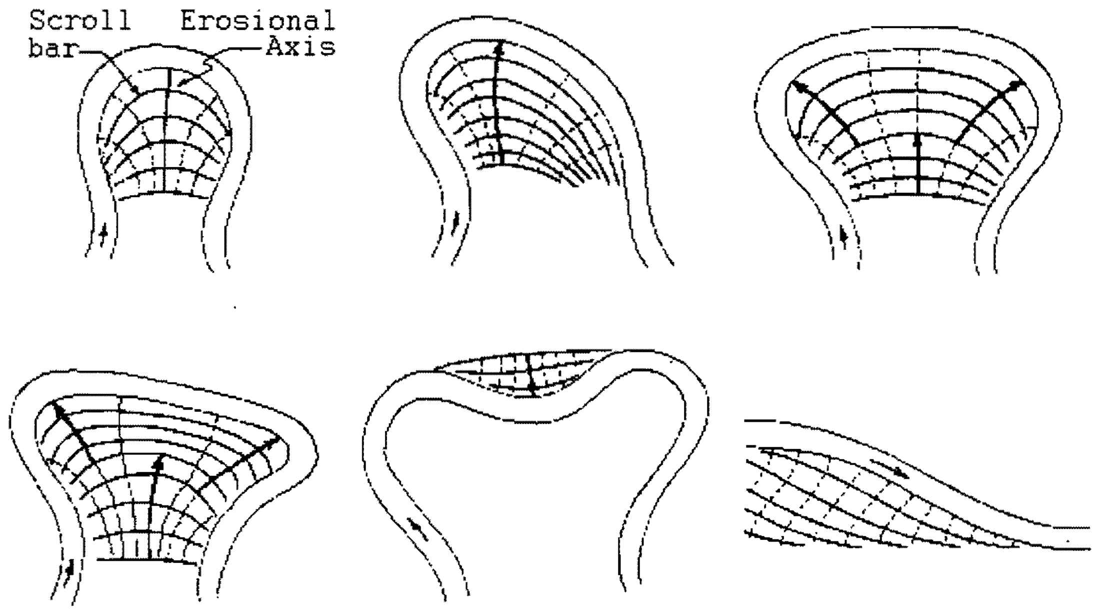

Figure 1. Lateral migration or meandering of natural stream channels.

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 reflects 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, dam construction, 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* as a natural consequence of bend migration in meandering streams is well documented. Similarly, the process of *chute cut-off* and development of *slough channels* in braided streams and low-sinuosity meandering streams is well documented. The complete abandonment of an entire reach of a stream, by *avulsion*, is also 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 occurring. In contrast, engineered artificial meander cut-offs and other forms of *channel straightening* to improve channels for navigation and reduce flood stages have been undertaken. 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 changes to channel morphology both upstream and downstream from the cut-off.

As a result of the varied ways in which natural stream channels change over time, channel behavior is difficult or impossible to predict in the long-term (and so the likelihood of a predicted behavior or a suggested solution being "wrong" is increased). Although the processes and responses are similar in small and large streams as long as flow is perennial, higher variability in smaller watersheds can produce events of low predictability that result in drastic changes. As a result, local modifications made to offset impacts such as downcutting, aggradation, or bank migration may result in unexpected impacts upstream or downstream which may take long periods of time before a new "equilibrium" results. This may require planning and design of additional control structures and appropriation of sufficient future funding for their installation and maintenance. Moreover, single unusual events (for example, discharge events of extremely low or high magnitude) or longer-term trends may destroy or reduce the effectiveness of features introduced to "correct" negative impacts.

Hence, it is important to emphasize that all modifications to stream channels should be viewed as temporary in nature. The best engineering solutions recognize the need to design "with nature" and accommodate natural channel changes over time, rather than the more traditional "hard" engineering approaches that require an attempt to limit and train the channel.

RECOMMENDATION 3 - THE NECESSITY FOR TRAINING

Because enhancement and restoration of stream channel habitats is a complex issue, advanced training beyond that typically given in traditional engineering curricula is necessary. As a result, in order to implement sound design and mitigation procedures, a multidisciplinary team approach is required. Apart from the traditional areas of engineering expertise, knowledge in such areas as fluvial geomorphology, landscape architecture, land use and land planning, wildlife management, and ecology is required. Selected TxDOT personnel and design/mitigation team members should receive additional training to assist them in developing reasonable approaches. A variety of training courses are currently available for hydrologists, engineers, and other specialists involved in water resource management. Courses such as those offered by D. Rosgen and others at the Wildland Hydrology Conference Center in Pagosa Springs, Colorado provide training in environmentally sensitive engineering design procedures for urban and rural drainage systems, and river restoration and management.

RECOMMENDATION 4 - THE NEED FOR COORDINATION

Multiple state and federal agencies are charged with monitoring and protecting surface water and stream channel habitats (for example, TNRCC, EPA, and USFW). TxDOT is required to interact with these agencies where stream-channel crossings and modifications are proposed.

In the future, and particularly with increasing urbanization, an even greater need for coordination of activities among these and other agencies is anticipated. It is already clear that effects of single channel modifications cannot be viewed in isolation, but must be viewed in the context of the stream reach or even the entire drainage basin in which they reside. This is particularly important if long-term forecasting of stream channel change is required. Future trends in development of a watershed have an impact, not only on the design of new structures, but on consideration of appropriate remediation for problems at existing structures.

In the future, any proposed design guidelines will need to emphasize the "whole watershed" approach in planning, mitigation, and remediation procedures (not case-by-case solutions viewed on an individual basis). This is the trend internationally, and makes common sense - but will require a new emphasis on data gathering at state/regional level.

RECOMMENDATION 5 - THE NEED FOR DATA COLLECTION

Environmentally sensitive design approaches require 1) that present conditions in the affected reach be well documented, and 2) that predictions be made regarding the future condition of the stream channel and surrounding environment. Predictions about the future direction and magnitude of change in the stream channel may be incorporated into the decision-making process for location and design of a structure, with the goal of preventing "negative" impacts before they happen. Such approaches require an extensive data-gathering system (and personnel to go with it) because the long-term behavior of channels is 1) difficult to predict, 2) unique to individual streams or reaches of streams (that is, very "site-specific"), and 3) much of the data needed to attempt this approach are not readily available in existing sources.

Data collection of this sort is a very difficult task - taking on in character something like an "environmental impact statement" typically done for the BLM-Department of Interior. There is a need for coordination of data collection among state and federal government agencies, as well as research and academic institutions.

1) The data required for decision-making would consist of the following:

a) - Position of proposed site within watershed

b) - Present conditions in watershed and site-specific information

- Urbanized, rural, agricultural, or natural setting
- Hydrological data
- Sedimentological data - character of sediment load
- Geological data - character of bed and bank material, bedrock character
- Water quality data
- Existing vegetation data
- Faunal data
- Visual or aesthetic data

c) - Existing, proposed, or possible future channel modifications upstream and downstream of present site

d) - Likely progress of on-going change in channel morphology and environments (brought about by previous modifications)

e) - Historical photographic and map coverage for the site vicinity

f) - Historical data on performance problems with other structures in watershed

g) - Prediction for future trends in development of watershed

2) The expected results of such an analysis would be:

a) - A qualitative assessment of likely extent of change in channel morphology and surrounding environments over a given span of years, OR a quantitative assessment through computer modeling (not yet possible but perhaps in future)

- Likely future changes in hydrology, discharge, flood magnitude, frequency
- Likely future changes in channel migration, downcutting, aggradation
- Likely future changes in channel bed material
- Likely future changes in vegetation, aquatic habitat

b) - Prediction of future conditions at site, based on above information

c) - Recommendations for location and design of structure based on prediction above

d) - A "family" of possible solutions could be advocated ranging from:

- Short life expectancy to long life expectancy of structure
- Inexpensive to expensive design and construction materials
- Conventional methods to unusual or experimental methods
- Under-designed to over-designed for hydraulic efficiency
- Artificial to natural character of structure
- Functional to aesthetic appeal of structure.

A suggested data collection format, comparable to that used for the existing TxDOT Bridge Inspection and Appraisal worksheets is included under separate cover.

Because of the difficulty of accurately accomplishing the task of data gathering and prediction at present, a set of model or study watersheds should be selected (in urbanized, agricultural, rangeland and natural settings) to serve as test cases over the coming decade(s). Data gathering of the sort described above could commence in these test watersheds. Design changes and modifications could be introduced in these test areas, as new structures become necessary, with the idea of testing their effectiveness or impacts over time. These could eventually serve as examples for statewide implementation.

RECOMMENDATION 6 - DEVELOPMENT OF GUIDELINES

There are several ways to improve upon the present TxDOT procedures. This requires that a discrimination be made between procedures employed prior to and during construction to minimize negative structural, environmental, and aesthetic problems *before* they occur ("prediction"), and procedures employed to address problems already in existence *after* they have occurred ("remediation"). These comprise different approaches and result in different classes of guidelines. Guidelines developed for use during the "design" phase (prior to construction) are intended to predict and hopefully prevent problems from occurring before the happen.

Guidelines developed for use during the "construction" phase are intended primarily to prevent temporary problems from occurring due to the short-term disturbance of the channel environment (for example, temporary increased sediment yield to channel, or removal of vegetation). In contrast, guidelines developed for use following construction are intended primarily for "remediation" of existing problems.

The first of these ("design" and "construction" guidelines) can be implemented through appropriate revision of the existing TxDOT Design Manual. However, full achievement of the goals of the existing TxDOT guidelines requires involvement of the Environmental Division of TxDOT at earlier phases in a project, not just during the later "approval" phase. Implementation of appropriate designs prior to construction and employing suitable procedures during construction will allow possible impacts to be addressed before or as they happen. Methods to forecast possible negative impacts and design to reduce their likelihood (selection of minimum impact location, stable channel configuration, preserve particular local natural features and selected vegetation features) can be developed with sufficient training and data collection (see above) and introduced during the design phase by personnel from the Environmental Division.

The second approach ("remediation") will require development of a new manual specifically intended to provide suggested methods for dealing with existing problems. This appears to be an area where at present there is little guidance other than "experience" and local knowledge available for TxDOT personnel in field offices. Most of the cases examined during field investigations for this report fall into this category.

Following is a suggested procedural outline for each of these classes of guidelines.

1) Guidelines for Prediction of Impacts Prior to and During Construction

Phase 1 - SITE INVESTIGATION

a) If the channel environment is previously undisturbed, prior to construction activities collect baseline information on conditions in the vicinity of a proposed channel modification (an "environmental impact analysis" of the sort described under Recommendation 5 above), including interfacing with other appropriate local, state, and federal agencies (moving ultimately toward the "whole-watershed" planning approach). If the channel environment is already disturbed by previous or on-going activities, collect baseline information from a similar nearby undisturbed channel in the same or nearby watershed.

b) Collect historical and current information on the successes and failures of similar modifications on channels of similar scale within this or nearby watersheds.

c) Make predictions about the future course of natural channel change at the proposed site (lateral migration, downcutting, widening, aggradation, etc.) applicable within the time frame of the proposed modification lifetime. This will require data gathering of the sort described in Recommendation 5 above.

d) Make decisions regarding suitable or most desirable habitat preservation or enhancement at the site. This will require developing a multiple-use philosophy described in Part II (below).

Phase 2 - DESIGN

a) If possible, locate the planned modification to result in minimum impact on natural channel behavior and habitat, as predicted above.

b) If possible, incorporate into the design features that will be aesthetically pleasing (color, texture, and materials) and encourage suitable inhabitation by desirable flora and fauna (bats, swallows, fish, etc.), according to a multiple-use philosophy (balancing cost and benefits, hydraulics, aesthetics, environment, and recreation).

c) Plan the construction schedule to result in minimum impact in the vicinity of the modification. If possible, select the appropriate time of year, plan to preserve selected vegetation areas, install sediment retention devices, and retain natural bed or bank material for later use in erosion control measures.

Phase 3 - CONSTRUCTION

a) If possible, during construction preserve, stockpile, and utilize suitable natural native or nearby materials for bank stabilization or erosion control devices. For example, suitable native rock material removed by excavation can be graded or sorted for later use. Soil removed during construction could be rolled, retained, and stored for later use. Large vegetation that must be removed during construction can be balled, set aside, and watered for later re-planting if possible.

Phase 4 - POST-CONSTRUCTION

a) Following construction, monitor the progress of soil and sediment retention devices, growth of reestablished vegetation, and follow-up on problems discovered. This is an area where TxDOT is presently deficient.

2) Remediation of Impacts Following Construction

Modifications following construction ("remediation") may be required to address negative impacts that have occurred around existing structures (primarily bank erosion, downcutting, aggradation). Suggested procedures will emphasize methods of dealing with "negative" impacts as they happen or after they happen. At the present time, these are probably more practical and attainable goals than predicting problems before they happen.

This approach will require drawing more intensively on experience of personnel at the local level. Recommendations or solutions proposed at state/bureaucratic level have the possibility (likelihood?) of failing because of lack of experience at the local level. Solutions proposed on an ad-hoc basis, or on a site-by-site method (as seems to be present practice), might also fail because of lack of broader experience in the area.

Proposals for successful remediation approaches will require a data gathering system to collect information from field offices on persistent problems/failures (areas of downcutting, aggradation, channel migration, vegetation problems, habitat loss) in each area, and particular successes (bat or swallow inhabitation, revegetation). These could be organized according to drainage basin or stream reach, or climatic/rainfall regime.

A standard form might be devised to report and monitor such problems. Personnel would be required at the state level to organize and monitor reports over the long-term. Local offices should be given flexibility or latitude to innovate. Successes might then be implemented throughout that particular drainage basin or climatic belt. Over the course of years, these data would serve to enhance predictive capabilities and could eventually be used for Task 1 (above). In the meantime, it is essential to produce a database of experience that would serve more broadly.

PART II
REVIEW OF COMMON PROBLEMS & APPROPRIATE SOLUTIONS

As part of this study, field examination of selected case studies was undertaken to isolate common structural, aesthetic, and environmental problems associated with channel crossings and modifications. From this, suggestions were developed for practical construction alternatives that minimize these problems. The goal is to provide engineering solutions that take into account the natural features of a stream channel and promote ways to preserve these natural areas. As indicated above (Recommendation 1), before addressing these problems it is important to separate structural, aesthetic, and environmental issues.

1) Structural Concerns - Structural concerns regarding channel crossings and modifications involve maintaining the safety of the motoring public and stability of the roadway through practices that enhance the hydraulic efficiency and performance of structures. The existing TxDOT design guidelines emphasize these practical concerns regarding the stability and safety of abutments and support structures at channel crossings. The objective of suggested procedures is to prevent damage to structures as a result of flooding, channel migration, sediment aggradation, or downcutting and to enhance the life expectancy of structures. These issues are not the primary subject of the present report.

2) Aesthetic Concerns - Aesthetic concerns include unsightly features associated with channel crossings that do not endanger the structure or result in any environmental impact. The objective of any suggested procedures would be to enhance the aesthetic quality of a structure and its surroundings, and to preserve or enhance its "visual quality." As much as possible, the goal would be to make a structure compatible with the natural landscape at the site. These issues are not the primary focus of the present report.

3) Environmental Concerns - Environmental issues regard maintaining a "wildlife corridor" and suitable natural habitat along the stream channel in the vicinity of a channel crossing. The objective of suggested procedures are to preserve or enhance aquatic habitat around a structure to offer minimum impact on the existing stream channel and bank habitat and, if possible, include features in the design to enhance existing habitat. These are the primary concern of the present report.

Selecting appropriate preventive measures or mitigation approaches requires defining what "natural" is. Some would advocate preservation of native species (even if less "attractive" and so less aesthetic), while other might advocate expansion or cultivation of "sport" species for recreation. What some groups or experts may consider natural, another might regard as a nuisance (e.g. raccoons, crayfish, bats, swallows, mosquitoes). A similar argument is also made regarding cultivation of native versus introduced species of both plants and animals. A decision must be made regarding whether it is desirable to maintain or enhance the existing habitat, or exercise the option of restoring past "native" conditions (e.g. selective removal of non-native species) in the vicinity of the crossing. Such procedures may also serve to improve opportunities for recreation around the structure, but this is not necessarily an environmental issue, and in many cases improved access may actually result in negative environmental impacts. Hence, a multiple-use philosophy must be adopted, along with a procedure for weighing the various impact scenarios.

Although often viewed as entirely negative, the existence of channel crossings result in some "positive" impacts as well. These include: 1) provision of habitation or nesting sites for swallows and bats, 2) development of deeper pools caused by scour at support structures for colonization by insects, crustaceans, fish, and amphibians, and 3) location of more permanent water pools at scour holes and cool shaded sites along the stream channel corridor that might not otherwise exist in the region (e.g. ephemeral streams in West Texas).

PROBLEM 1 - Location and Alignment of Crossing

Many or most structural, aesthetic, and environmental problems associated with channel crossings can be avoided by selection of an optimum location and roadway approach for the crossing. The existing TxDOT design guidelines point out the potential problems associated with choosing a poor location for the crossing. Nevertheless, in several sites examined for this report, the underlying cause for problems experienced at the crossing was the initial poor location on the outer bend ("cut bank") of a meander loop where the rate of lateral channel migration is most rapid (Figure 2 and Figure 3). Siting the bridge at this location promotes rapid impingement of the channel margin on the bridge abutment or approaching roadway, and necessitates eventual bank protection measures or channel "training" efforts that would otherwise have been unnecessary. These in turn result in aesthetic and environmental concerns.

Selecting an optimum location for a channel crossing requires anticipation of likely future channel behavior. Study of aerial photography or county soil survey maps of the area can accomplish this. Inspection of these usually will reveal 1) the part of the flood-plain subject to recent channel migration, and 2) remnant "scroll topography" in the active part of the river floodplain that records the direction of past channel migration. The likely extent and direction of future channel migration can be approximated in this manner.

PROBLEM 1 - EXAMPLE A

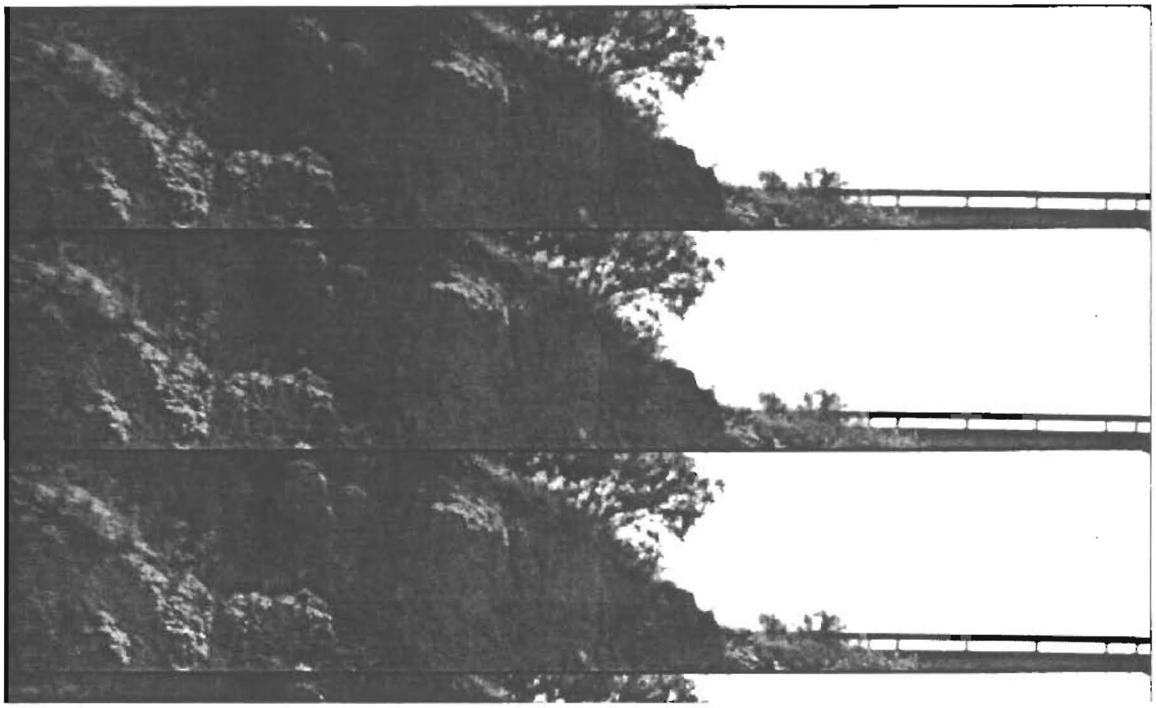

Figure 2. Photograph viewing east from west of U.S. Highway 83 bridge crossing the Pease River in Childress County showing impingement of channel margin on north abutment. Northward migration of the erosional cutbank on this meander loop is endangering the abutment on the north side of the bridge. Local rock rubble was dumped on the upstream (west) side of the abutment in an attempt to slow erosional retreat of the bank. Location of this crossing at the apex of a meander loop resulted in predictable endangerment of the abutment placed on the erosional cutbank. A new bridge structure under construction (at time of visit) to the east of existing bridge will probably experience similar problems as channel migration proceeds. One approach to prevent this problem would be to examine aerial photographs of the channel meander system and locate the abutments such that they are outside the meander bandwidth.

Figure 3. Bridge crossing the North Pease River on State Highway 94 in Childress County showing impingement of channel margin on north abutment. Northward migration of the erosional cutback on this meander loop is endangering the abutment on the north side of the bridge. No bank protection measures have been attempted. Location of this crossing at the apex of a meander loop resulted in predictable endangerment of the abutment placed on the erosional cutbank. The bridge is providing habitat for swallows (note nests underneath structure).

PROBLEM 2 - Drainage Control During Construction

An abnormally high sediment load may enter a stream channel due to poor control of runoff on disturbed soil surfaces in the vicinity of a channel crossing (Figure 4). This occurs primarily during and immediately following construction, and has been the subject of much previous study and regulation. Although this poses no structural problem, and only a temporary aesthetic concern, an increased sediment load to the channel often results in environmental problems. Increased bedload sediment deposition in the channel smothers bottom-dwelling invertebrates and aquatic vegetation. Increased suspended sediment in the water column may lead to reduced light penetration, prevention of plant growth, and reduction in bottom invertebrate populations. This leads to subsequent negative effects on riparian habitat that may have a long recovery time. The influx of sediment to the stream channel during and immediately following construction may be properly addressed with installation of temporary measures such as silt fences, synthetic mats, and straw bales. The existing TxDOT guidelines provide suggestions for the proper deployment of these measures. However, these existing procedures are often not followed correctly, materials are sometimes improperly installed, and with little or no follow-up maintenance. In some cases, when erosion control measures are properly deployed at a construction site and maintained, through inspection may not occur in the aftermath of installation at other portions of the site. For example, on the opposite bank from the point shown in Figure 4, erosion had progressed from the sheet to the rill stage on the highway embankment approaching the bridge. The matting that had been placed on the embankment to prevent erosion had not been maintained properly. If procedures already in place were more strictly adhered to, this problem could be minimized.

PROBLEM 2

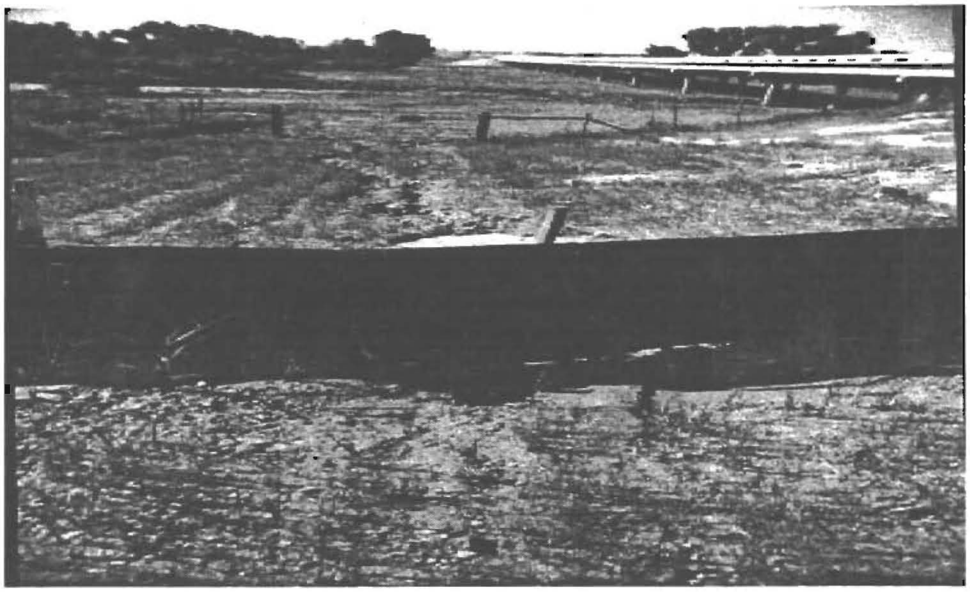

Figure 4. Failed silt fence and erosion of soil and grass cover in the east roadside channel north of the U.S. Highway 83 bridge crossing of the Middle Pease River in Childress County. Poor control of road surface runoff immediately following construction and prior to establishment of the grass lining in the roadside channel, and lack of follow-up maintenance, has resulted in erosion.

PROBLEM 3 - Drainage from Structure, Abutment, & Adjacent Roadside Channel

The presence of a channel crossing itself seldom poses much or any environmental impact, however poor control of surface water runoff from the roadway, bridge abutments, and roadside ditches can result in structural and environmental concerns (Figure 5 and Figure 6). These problems may be properly addressed by installation of permanent velocity control structures and sediment/infiltration basins. Proper design and maintenance of drainage channels for carrying water from the highway to the roadside ditch must be stressed in all areas of the state. The grades of the roadside ditches at the crossing must also be examined and appropriate measures such as grade control devices or paving the installed channel to minimize erosion at these critical points where the runoff velocities increase due to the steepening slope of channel.

PROBLEM 3 - EXAMPLE A

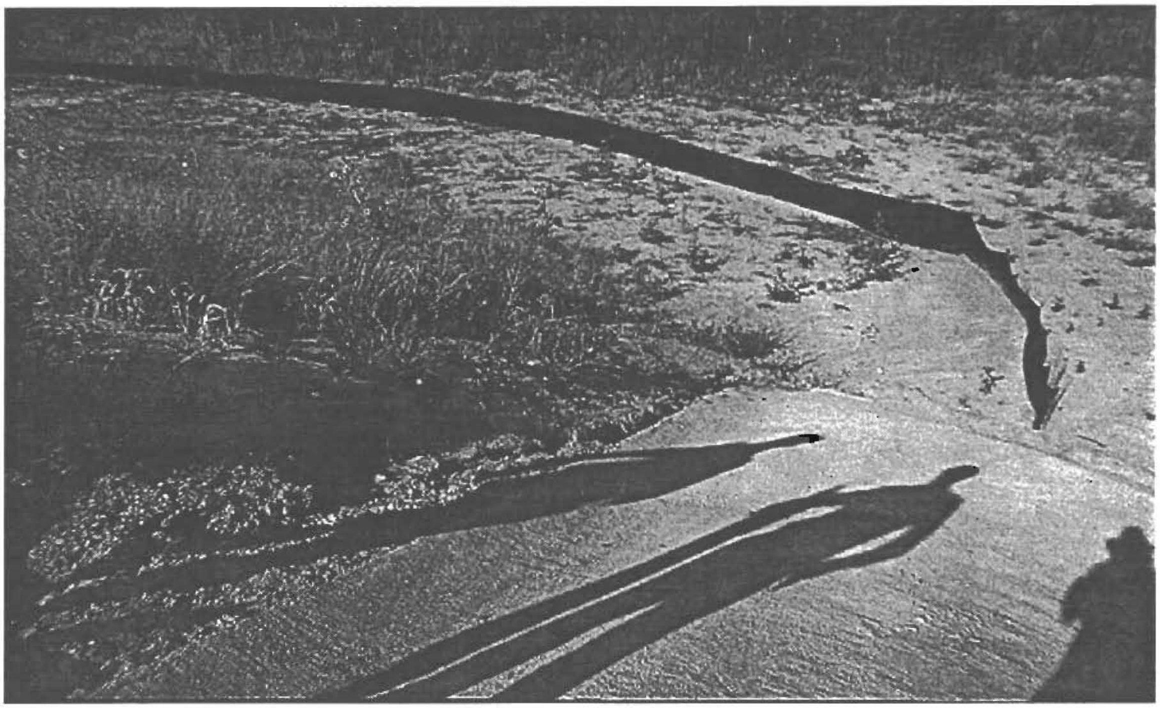

Figure 5. Erosion of the western side of the south abutment of the U.S. Highway 83 bridge crossing the Middle Pease River in Childress County. Road surface runoff has failed to flow in the designed channel within cast-in-place concrete abutment, resulting in erosion of soil and grass lining along flank of abutment and in adjacent roadside ditch.

PROBLEM 3 - EXAMPLE B

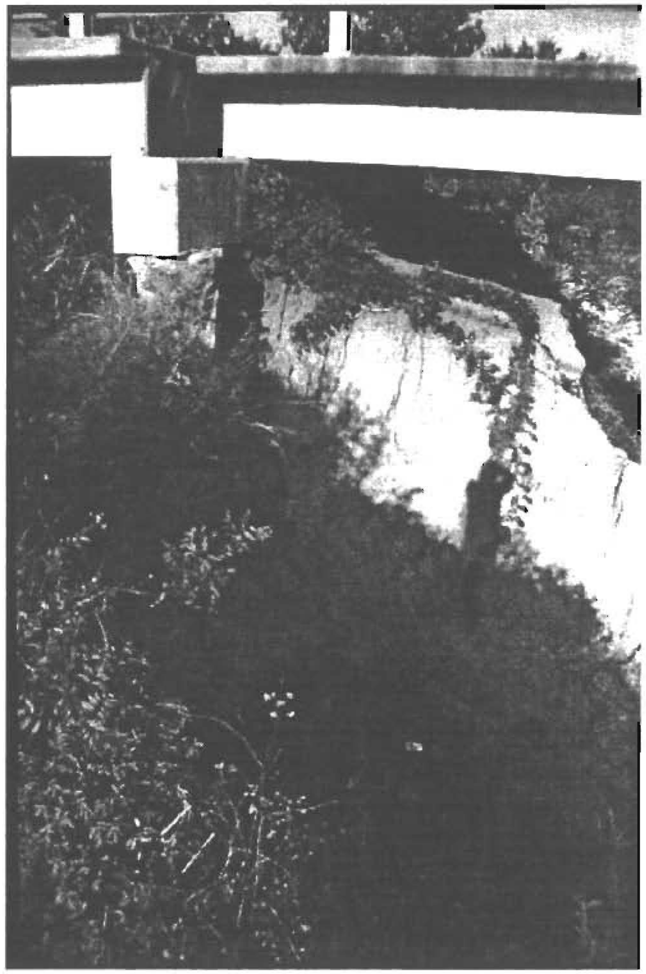

Figure 6. Erosion of north abutment beneath FM 68 bridge crossing the North Sulfur River in Fannin County. Uncontrolled runoff from road and bridge surface is eroding the abutment.

Most crossings examined for this study, including new construction, illustrate poor designs (from an environmental perspective) for drainage from bridge abutments and roadside channels. Natural vegetation or flexible permanent lining for roadside drainage channels is preferable for aesthetic and environmental purposes since they are able to trap and absorb particulate and some dissolved contaminants in runoff water. Use of rigid concrete surface in roadside channels may be more effective hydraulically, but less aesthetic than a natural vegetation lining. Rigid channel linings probably do not constitute an environmental problem.

Additionally, at many of the crossings that were examined during this study, scour holes and gullies had developed from the water draining through weep holes placed to remove water from the bridge. The water exiting from the weep holes had sufficient force to erode large scour holes in the embankment with accompanying gullies to drain to the water channel. Ways must be found to remove the water from the bridge quickly without instigating major maintenance of the fill material at the bridge abutments. Bridge drain water should be deposited into the channel area rather than on the abutment surface.

PROBLEM 4 - Bank Erosion Control

Selection of appropriate materials for control of bank erosion in the vicinity of a channel crossing can result in dramatic improvement in aesthetic qualities and may reduce the environmental impact of the structure or even enhance habitat in the vicinity. Several crossings examined for this report illustrate poor choice and haphazard deployment of bank erosion control measures (Figures 7 to 10). The common use of construction waste material (concrete rubble, bricks, broken asphalt pavement) for stop-gap bank erosion control measures adjacent to bridge abutments is not appealing aesthetically, and may not be very effective in mitigating the structural problem (rapid channel migration), but probably does not constitute an environmental issue. However, this practice does commonly encourage dumping of solid waste by the motoring public that may ultimately pose a legitimate environmental concern owing to chemical contamination of runoff water. Use and establishment of suitable "natural" materials such as trees, shrubs, vines, and grasses; or materials native or adaptable to the local area for bank protection, is desirable both aesthetically and environmentally.

A computer program (ENDOW - Environmental Design of Waterways) is available through the U.S. Army Engineer Waterways Experiment Station that assists in selecting appropriate streambank protection measures with various environmental concerns in mind.

PROBLEM 4 - EXAMPLE A

Figure 7. FM 1550 bridge crossing Brushy Creek in Fannin County (above) with concrete rubble dumped to mitigate impingement of flows on west channel bank and abutment of bridge.

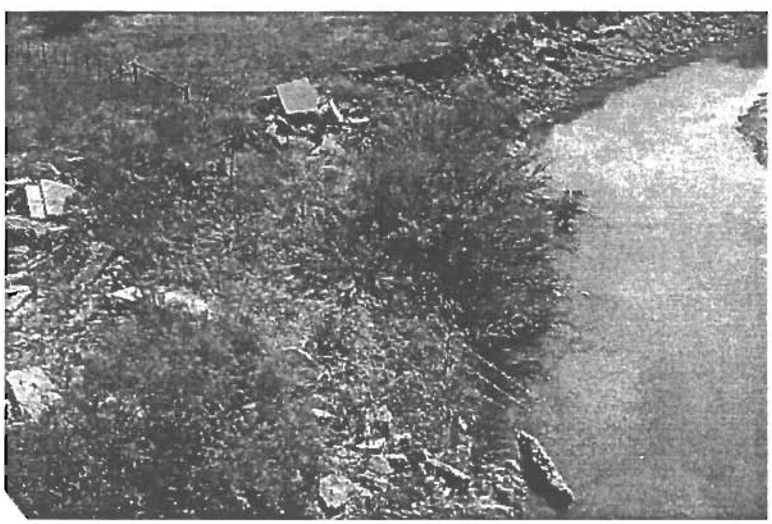

Figure 8. FM 267 bridge crossing the North Wichita River in Childress County showing impingement of margin on south abutment. Southward migration of the erosional cutback on this meander loop is endangering the abutment and approach roadway on the south side of the bridge. Concrete, brick, and asphalt rubble has been dumped on the upstream (west) side of the abutment in an attempt to slow erosional retreat of the bank. This haphazard bank erosion control has fostered illegal dumping and littering in the same area, and resulted in aesthetic and environmental concerns.

PROBLEM 4 - EXAMPLE B

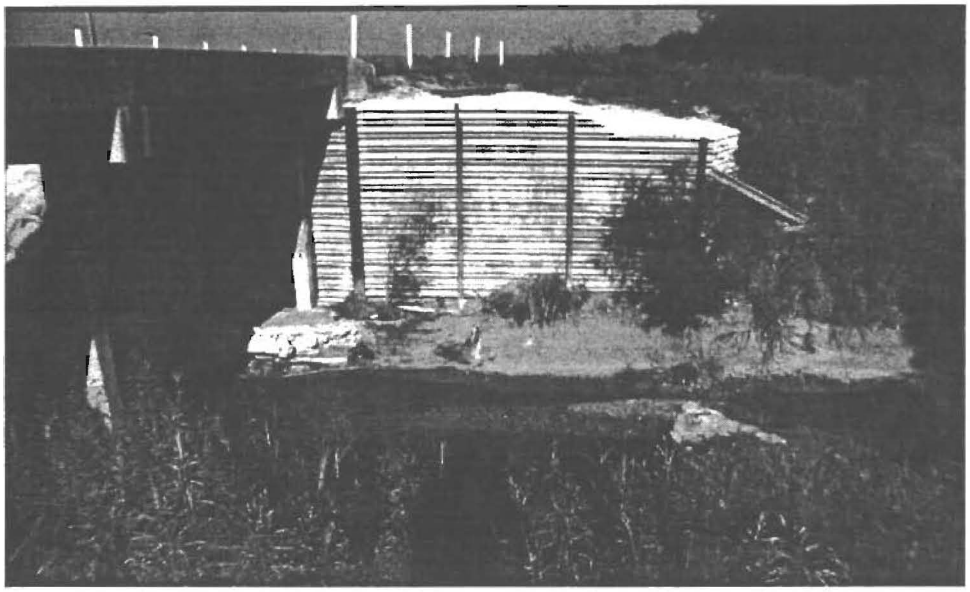

Figure 9. FM 1550 bridge crossing Brushy Creek in Fannin County. Lowering of the channel bed (approximately two meters) by down cutting resulting initiated by the channel lowering of the Sulfur River is endangering the east abutment of the bridge. Guardrail steel was used to construct a crib for crushed-rock backfill to stabilize the east abutment beneath the structure.

Figure 10. Concrete rubble dumped on the upstream upside of the abutment was covered in-place with poured concrete in an attempt to slow erosional retreat of the bank. Such "unconventional" measures pose an aesthetic and perhaps an environmental concern.

PROBLEM 5 - Channel Bed Degradation

Lowering of the bed of a channel by erosional down cutting can occur over the entire length of a stream channel and its contributing tributary drainages in response to various natural or man- made problems occurring either upstream or downstream of a crossing. This is a long-term process that is usually not related to the presence of the channel crossing structure itself. Nevertheless, this process poses a definite structural, environmental, and aesthetic concern at channel crossings (Figures 11 to 14). Bridge abutments and support structures may be endangered, channel bed sediment and vegetation are lost, and ultimately rigid drop structures and bank erosion control measures must be installed. An environmental impact can result since drop structures impact the movement of fish upstream and downstream from the structure. Although the underlying cause of regional down-cutting is not the responsibility of TxDOT, the remediation of its effects poses a significant concern and cost impact in some watersheds.

In contrast to regional downcutting, channel bed degradation may also be localized in the vicinity of channel crossing structures. This is a common short-term process ("scour") that often is a direct result of the structure itself. Scour caused by failure to accommodate the full discharge during peak events, scour around the base of bridge piers, poor design, installation, and maintenance of runoff control structures for the bridge or highway at the crossing site can initiate or augment adverse structural impacts in the bridge or its abutment in many instances. Although later attempts to inhibit scour often result in an adverse aesthetic impact (e.g. deployment of bank erosion control materials), this seldom creates an environmental problem.

PROBLEM 5

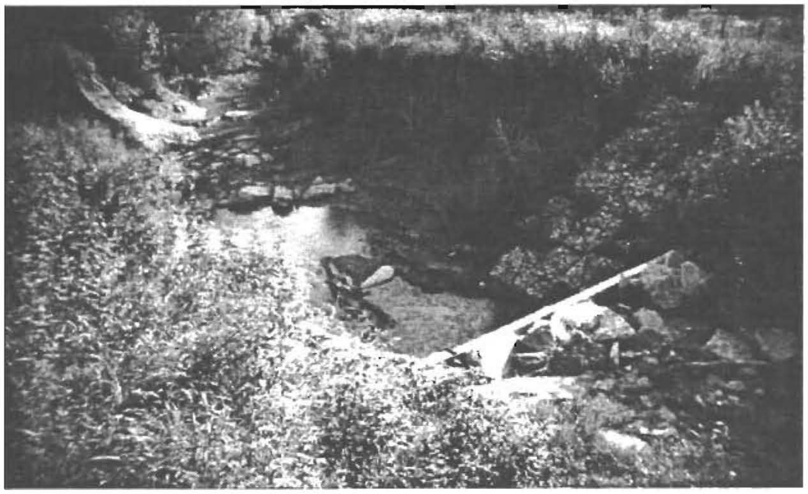

Figure 11. FM 1550 bridge crossing Brushy Creek in Fannin County showing effects on tributary drainages of lowering in channel bed by regional down cutting of the Sulfur River.

Figure 12. A drop structure constructed of steel H-beams and pre-cast concrete slabs was installed downstream from the structure to halt additional lowering of the channel bed. Although this is an appropriate mitigation strategy, it completely disrupts low stage flow.

PROBLEM 5 (CONTINUED)

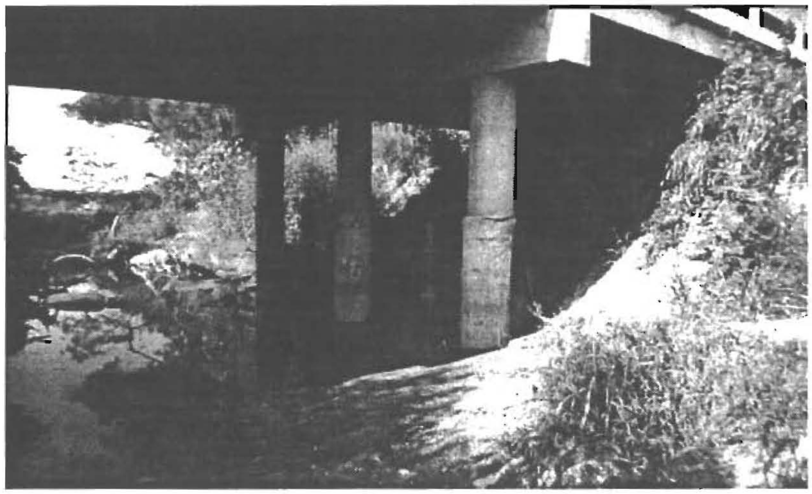

Figure 13. Erosion of the channel bed is endangering bridge support structures and abutments, also resulting in environmental and aesthetic problems. Artificial straightening in the trunk stream channel downstream (Sulfur River) caused at least a 2-meter drop in channel bed elevation in this tributary drainage.

PROBLEM 5 (CONTINUED)

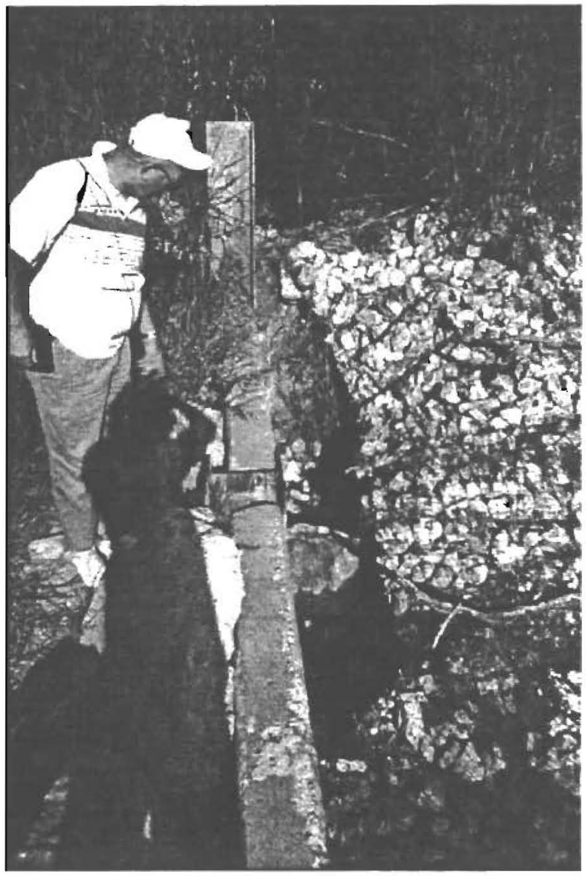

Figure 14. Intensified erosion on the downstream side of the drop structure required installation of wire basket gabions for erosion control, which are now failing because of foundation problems.

PROBLEM 6 - Impingement of Channel on Abutments

Endangerment of a bridge abutment and/or roadway approach by natural channel migration is a common structural stability problem at channel crossings. Natural channel migration results in erosion and bank failure over time, particularly on the outside (concave) banks of meandering stream channels. This erosion will take place regardless of whether or not a channel crossing is present, but it may be intensified if improper design fails to readily convey the entire flow during maximum discharge events. Although bank erosion poses a structural concern, and erosion control measures deployed to slow it may pose an aesthetic concern, seldom does this pose an environmental problem.

This problem is best addressed in the design phase by choosing an optimum location for the crossing (at relatively straight or "cross-over" reaches), and placement of bridge abutments well beyond the present limits of the channel in order to span the entire region likely to experience channel migration. If this is not possible, and instead existing impacts must be mitigated, selection of aesthetically and environmentally appropriate bank erosion control materials is the most important issue (Figures 15 to18). This problem was the most common one encountered in the case studies examined for this report, and was usually brought about by improper alignment of the approach roadway and crossing relative to flow in the channel.

PROBLEM 6

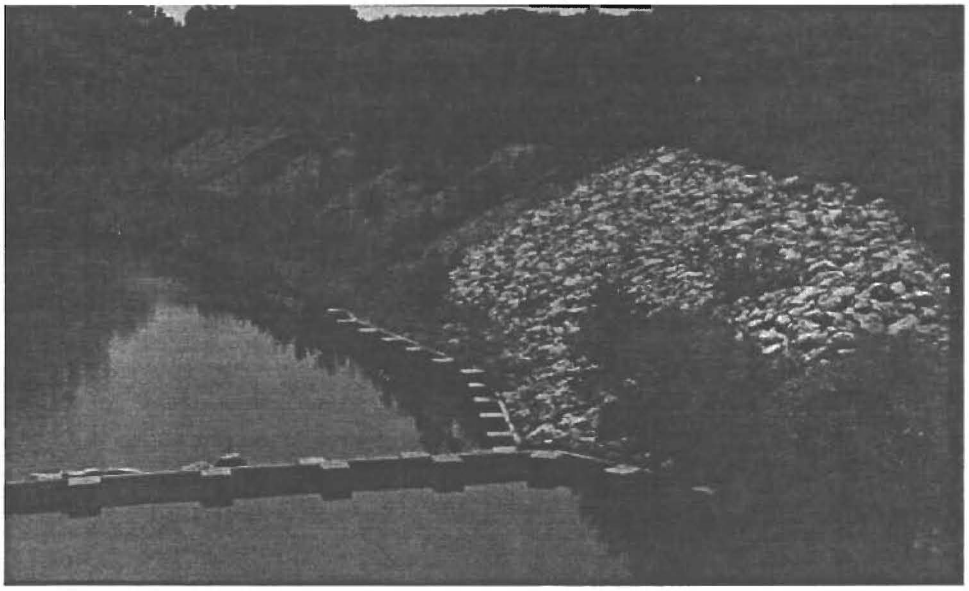

Figure 15. Grade control structure on the downstream side of the bridge crossing Bear Creek on the Northbound Spur 97 in Tarrant County.

PROBLEM 6 (CONTINUED)

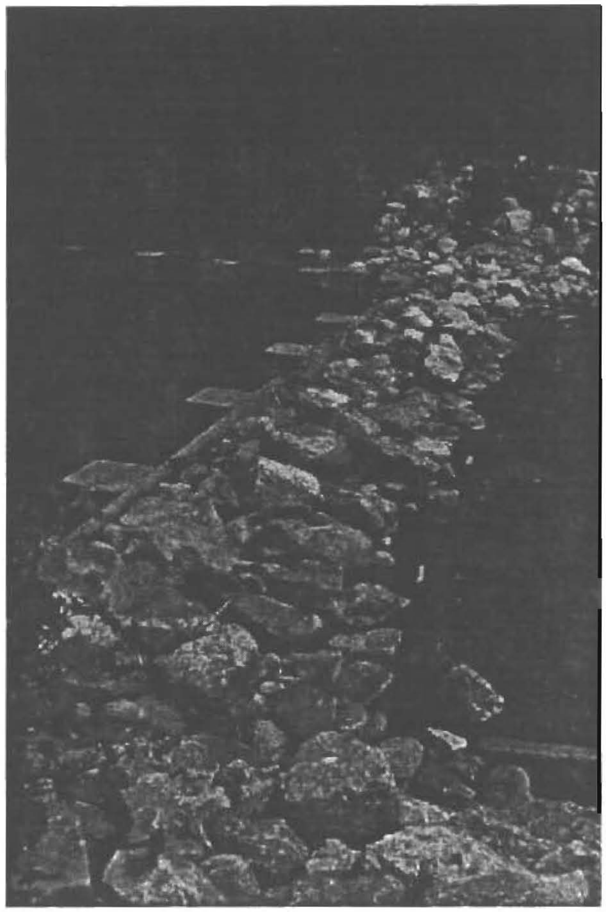

Figure 16. Downstream side of the grade control structure.

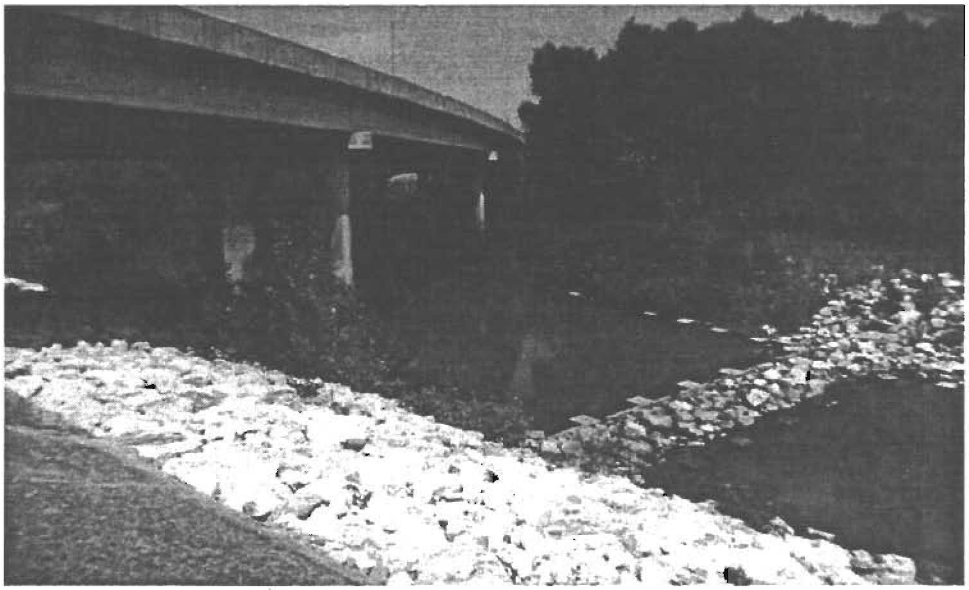

Figure 17. Grade control structure and riprap on south abutment to protect against channel flows impinging on the abutment.

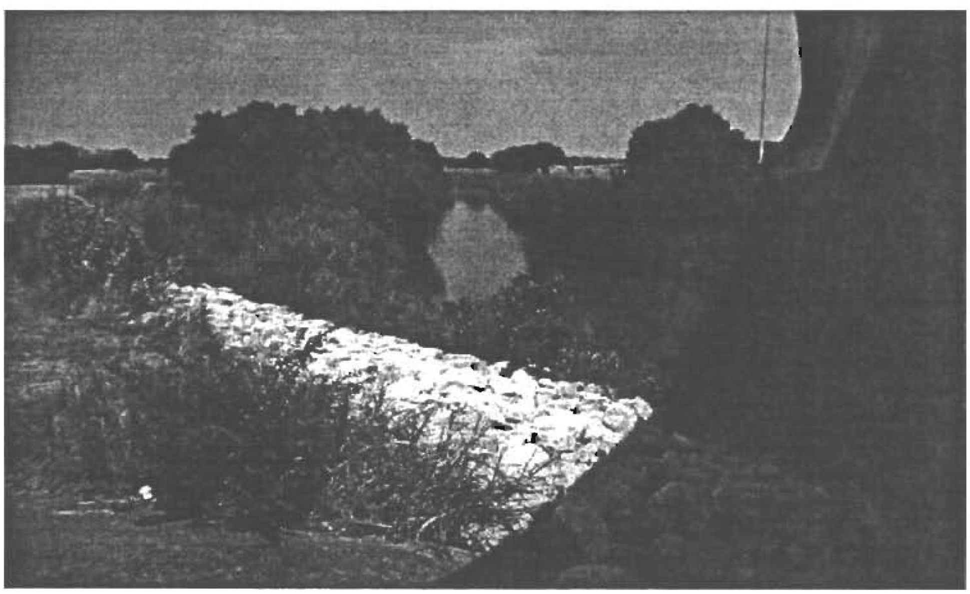

Figure 18. Picture upstream of the bridge showing the riprap and channel direction change which occurs at the bridge site.

PROBLEM 7 - Straightening of Channel

Artificial straightening of a natural channel is a type of modification that is best avoided. Straightening of a channel results in an increase in slope that, depending on the scale and length of channel modified, may lead to upstream-propagating degradation of the channel bed and corresponding downstream sediment aggradation (Figures 19 to 21). Such changes in bed elevation may result in structural, aesthetic, and environmental problems both upstream and downstream from the crossing. The severity of these problems depends on the magnitude of the attendant slope increase. The same problems associated with channel bed degradation described above (Problem 5) often result from channel straightening.

If straightening cannot be avoided, the new alignment should be as close as possible to the natural curvature, slope, and bed material of the original channel. In severe cases, grade control "drop" structures, such as check dams may have to be installed at the upstream and downstream ends of the straightened reach or at intervals along its length to maintain the desired channel grade. However, these interrupt flow in the channel, particularly at low discharges, and may prevent upstream or downstream exchange in aquatic species. This is a serious environmental concern for migratory species. However, plunge pools that typically form on the downstream side of check dams, offer sites for sport fishing (and habitation sites perhaps for native species as well) and may be regarded as a positive aesthetic impact.

More closely spaced and less severe drop structures are preferable (environmentally) to major check dams that completely interrupt flow during low discharge. An alternative approach is to anticipate in advance and allow the bed elevation to fall, accommodated gradually over the affected reach. It should be remembered that meandering stream channels in their natural state will episodically cut-off meander loops, resulting in similar natural channel slope adjustments over time, and so this form of channel straightening may be viewed as a natural process.

PROBLEM 7

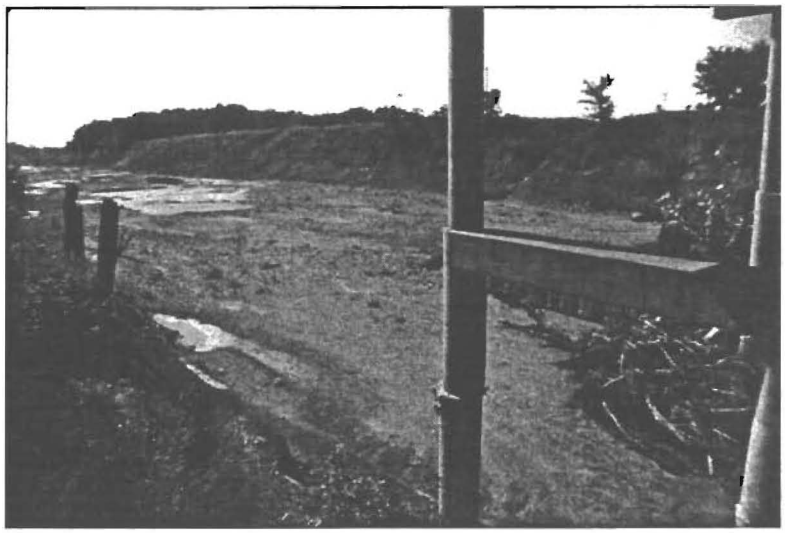

Figure 19. This is a view looking upstream from the FM 2990 bridge crossing the North Sulfur River in Fannin County. In response to the straightening of the Sulfur River Channel, dramatic lowering of the channel bed by regional down cutting has occurred. The drop in channel bed elevation was caused by the artificial straightening of this reach of channel that resulted in the steepening of gradient. The ring shown on the concrete pier shows the level of the channel when the pier was poured.

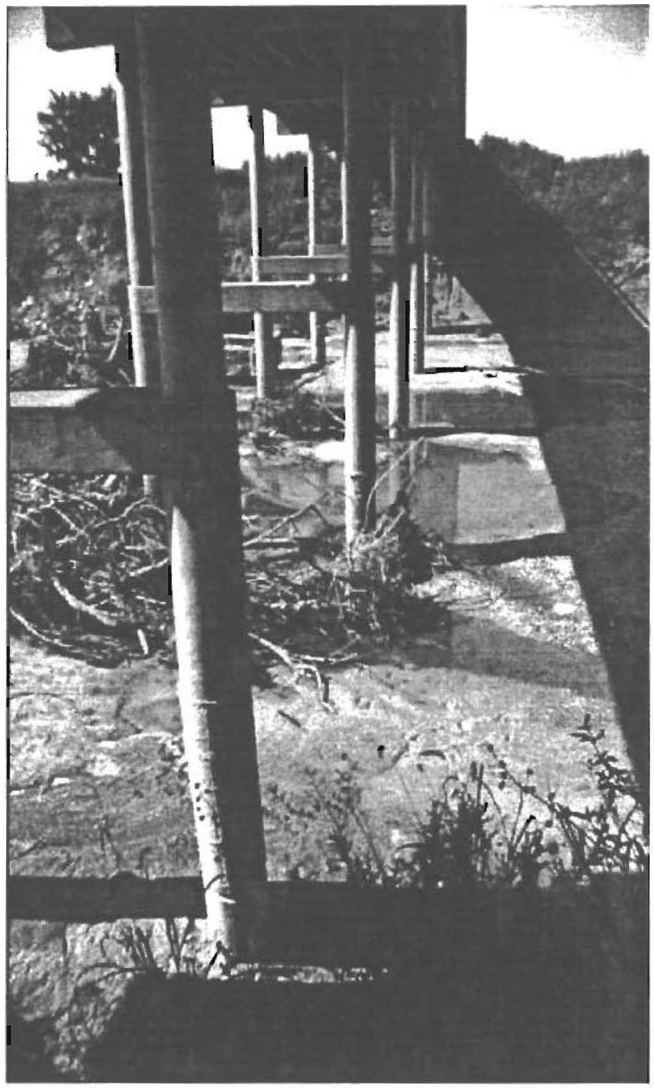

Figure 20. Photograph of view north to show the channel cross section at the bridge. The level of the channel at the time the piers were poured can be seen on by the markings on the two closest piers. Erosion of the channel bed is endangering all the bridge support structures and both abutments.

PROBLEM 7 (CONTINUED)

Figure 21. Photograph with a view east to show a view of the channel downstream from the bridge. Natural channel alluvium has been scoured away by erosion. The banks are subject to slope failure and to erosion. The channel bottom is bedrock with a few scattered gravel drifts over the surface.

PROBLEM 8 - Relocation of Channel

This is among the most severe of channel modifications, and should be avoided as much as possible (Figures 22 and 23). Where no alternative is possible, the proposed new channel alignment should maintain the dimensions, slope, bed material, and meander pattern of the existing channel. If the existing channel slope cannot be maintained, grade control structures will be required as discussed above, and these may result in environmental concerns. Planning of new channel locations and alignments requires training in environmentally sensitive design procedures for both urban and rural drainage systems. Courses in river restoration and management (such as those described under Recommendation 3, above) are essential for proper development of such severe channel modifications.

PROBLEM 8

Figure 22. Modifications to an unnamed tributary of the Navosota River near SH 6 in Brazos County. The drainage way on the left drains highway runoff toward the observer and makes a left hand turn into the drainage channel to the right which transports runoff from the watershed east of the highway. This channel flows away from the observer to a sharp curve where the concrete channel ends and an earthen channel starts at the top of the photograph.

Figure 23. This shows channel conditions just downstream from the bend shown in Figure 22 to another sharp bend to the left in the earthen channel some 100 feet downstream.

PROBLEM 9 - Access to Channel by Livestock and for Recreational Activities

Highway channel crossings commonly allow livestock access to local water and shade which results in trampling of the banks and bed of the channel, and fouling of water with waste and sediment (Figure 24). This problem is particularly apparent in the more arid regions of West Texas where stream flow is ephemeral and shade is rare. This poses both an aesthetic and environmental concern.

Similarly, access by the public for recreational activities (legal or otherwise) at channel crossings (boating, fishing, and bird watching) may result in either positive or negative environmental and aesthetic impacts. In stream channels with ephemeral discharge, channel crossings provide access by off-road vehicles (motorcycles and sport four-wheel drive) that may also constitute an aesthetic and environmental concern upstream and downstream of the crossing itself. Access to the channel by the public results in litter and graffiti that poses an aesthetic concern, and also enhances bank degradation and may result in interference or destruction of wildlife habitat. Designs that restrict access from the approach roadway to areas around channel crossings may reduce this concern, but this is a matter that probably will require broader legislative or regulatory action.

PROBLEM 9 - EXAMPLE A

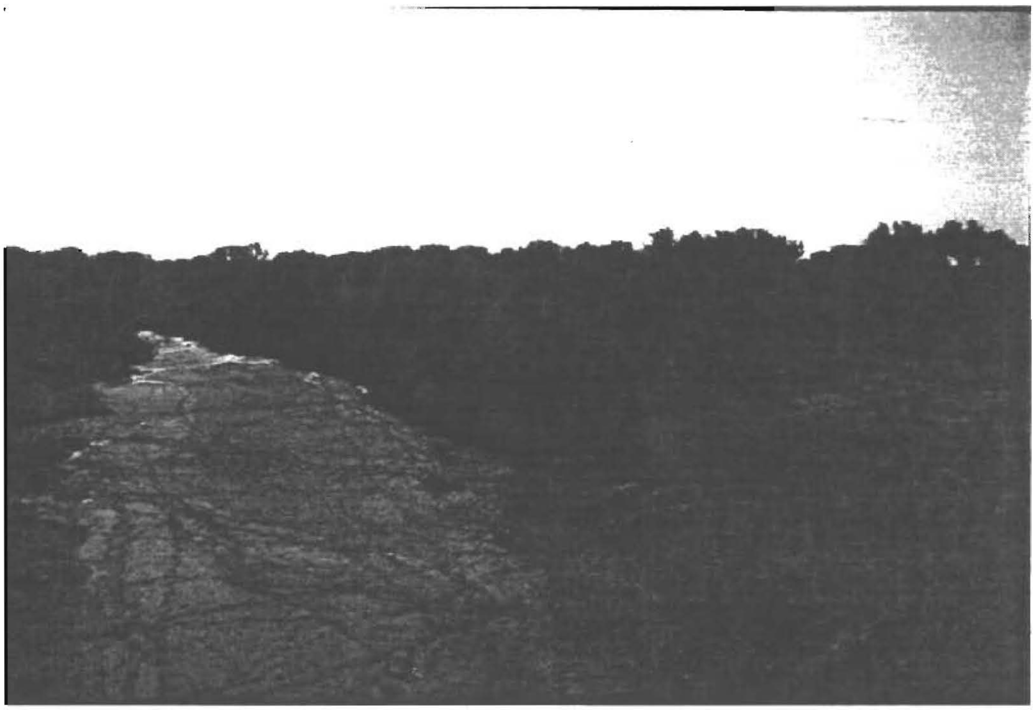

Figure 24. Channel of the Pease River immediately upstream from the crossing on State Highway 6 in Hardeman County showing accelerated bank erosion by livestock entering the channel adjacent to the northern abutment.

PROBLEM 10 - Vegetation and Debris in the Channel

Removal of vegetation from the channel and banks during bridge construction is often required. Clearance of established vegetation should be kept to a minimum. This is of particular concern when channel straightening or relocation is undertaken. Necessary removal of vegetation, fallen trees, and debris drifts should be undertaken to result in as little impact as possible. Growth of vegetation around channel crossing structures promotes environmental quality and may have little affect on the hydraulic efficiency of the structure. Debris jams on the upstream side of bridge support structures may pose a structural concern, but seldom results in aesthetic or environmental problems. Natural vegetation in the channel and along the banks is also the best form of erosion control measure, both on aesthetic and environmental grounds (Figure 25).

Preservation of diverse riparian vegetation, including aquatic plants and bank vegetation, as well as the debris they produce, is probably the single most important means of protecting stream channel habitat. Post construction environmental impacts can often be correlated with the extent to which bank vegetation has been cleared. Reduction of channel vegetation has a direct impact on loss of habitat for many small mammals and birds, and indirectly results in loss of amphibian species by removing slow moving slack-water areas. Similarly, removal of vegetation leads to loss of shade and cover necessary for many fish species. The most successful structures for maintaining or re-establishing fish populations are natural vegetation, rock, and log structures.

PROBLEM 10

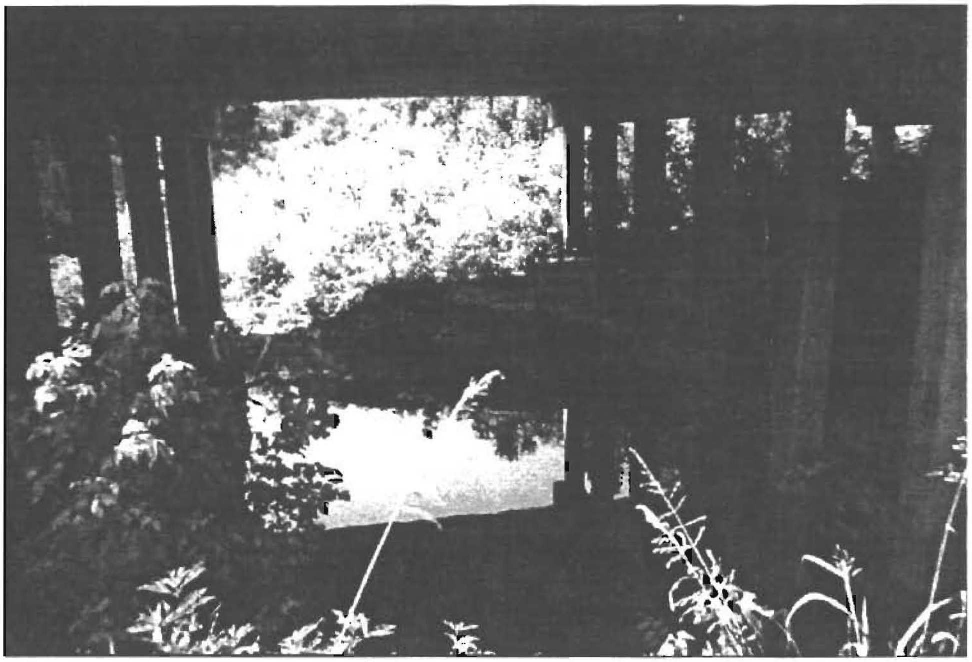

Figure 25. View upstream of unnamed stream at FM 158/1179 in Brazos County. Channel was modified in 1992, with straightening and relocation from original site. Some channel degradation is present beneath the bridge structure, but vegetation established on channel banks and bottom is successfully maintaining the new channel section. This site will require monitoring during subsequent flood events to determine if the channel was successfully modified.