An Analysis of Design Features in Mitigating Highway Construction Impacts on Streams

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In March 1986 the Pennsylvania Department of Transportation and FHWA completed Research Project 84-31, *An Analysis of Design Features in Mitigating Highway Construction Impacts on Streams.* During this research project and a previous research project, the biological conditions were evaluated in two streams before, during, and after the construction of two large arch culverts and the relocation of about 1 mi of stream. In addition, the cost and effectiveness of the mitigative design features incorporated into the culverts and relocated stream channels to promote recovery of the biological communities were analyzed. The results of the research clearly showed that the mitigation was effective in accelerating stream recovery. Postconstruction habitat and aquatic populations were similar to or better than under preconstruction conditions. The overall cost of the project with mitigation was slightly less than that of the project without mitigation. The results of Research Project 84-31 are documented in the Final Report completed in March 1986. The highlights of the research presented in that report are given. This research complements Research Project 79-10, *The Impact of Stream Relocation on Fish Populations and Bottom Fauna.*

In March 1986 the Pennsylvania Department of Transportation (PennDOT) and FHWA completed Research Project 84-31, *An Analysis of Design Features in Mitigating Highway Construction Impacts on Streams (1).* During this research project and a previous research project the biological conditions were evaluated in two streams before, during, and after the construction of two large arch culverts and the relocation of about 1 mi of stream. In addition, the cost and effectiveness of the mitigative design features incorporated into the culverts and relocated stream channels to promote recovery of the biological communities were analyzed.

Construction of the missing link of the Allegheny Valley Expressway between Kittanning and Pittsburgh, Pennsylvania, which was completed in 1985, was the subject of this research. The expressway construction near Tarentum, Pennsylvania, required relocation of 5,150 ft of Bull Creek and 1,815 ft of Little Bull Creek and construction of two concrete arch culverts, 885 and 449 ft long, respectively, on Bull Creek and Little Bull Creek. A unique aspect of the Bull Creek relocation and culvert design was that as a flood channel it had to safely carry a 50-year frequency flood as well as provide a recreational fishery. Figure 1 shows the relocated Bull Creek channel.

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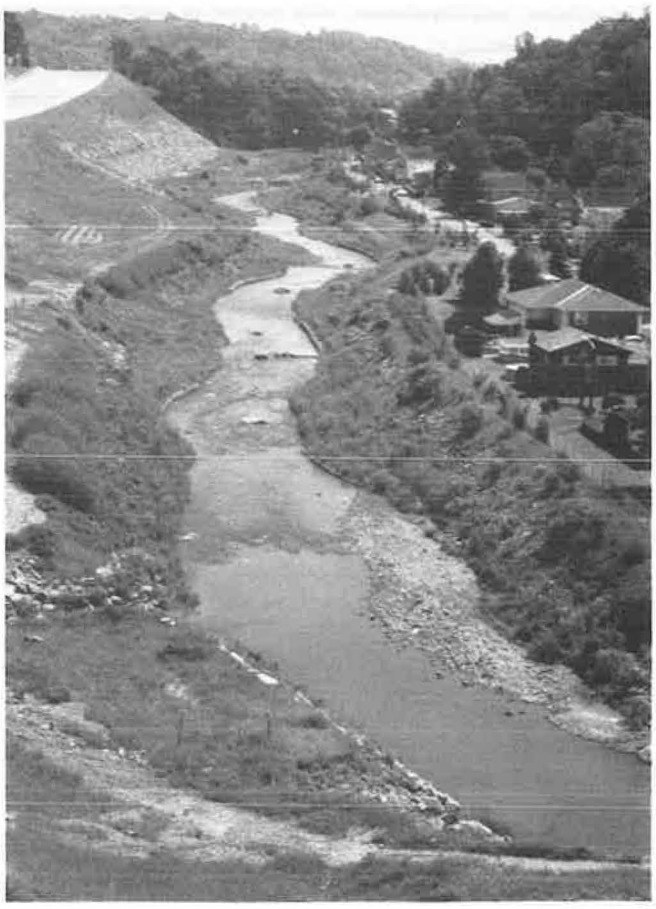


FIGURE 1 Downstream view of relocated Bull Creek channel along Bull Creek Road.

PROJECT DEVELOPMENT

Four construction sections (5D–5G) made up the final portion of the Allegheny Valley Expressway construction project. Figure 2 shows Bull Creek and Little Bull Creek with respect to these final sections. Although most of the expressway was designed before the passage of the National Environmental Policy Act of 1969 (NEPA) and completed in the 1970s, these sections were designed but not constructed because of the lack of funding. In 1976 federal funding became available and PennDOT and FHWA prepared and circulated an Environmental Impact Statement (EIS).

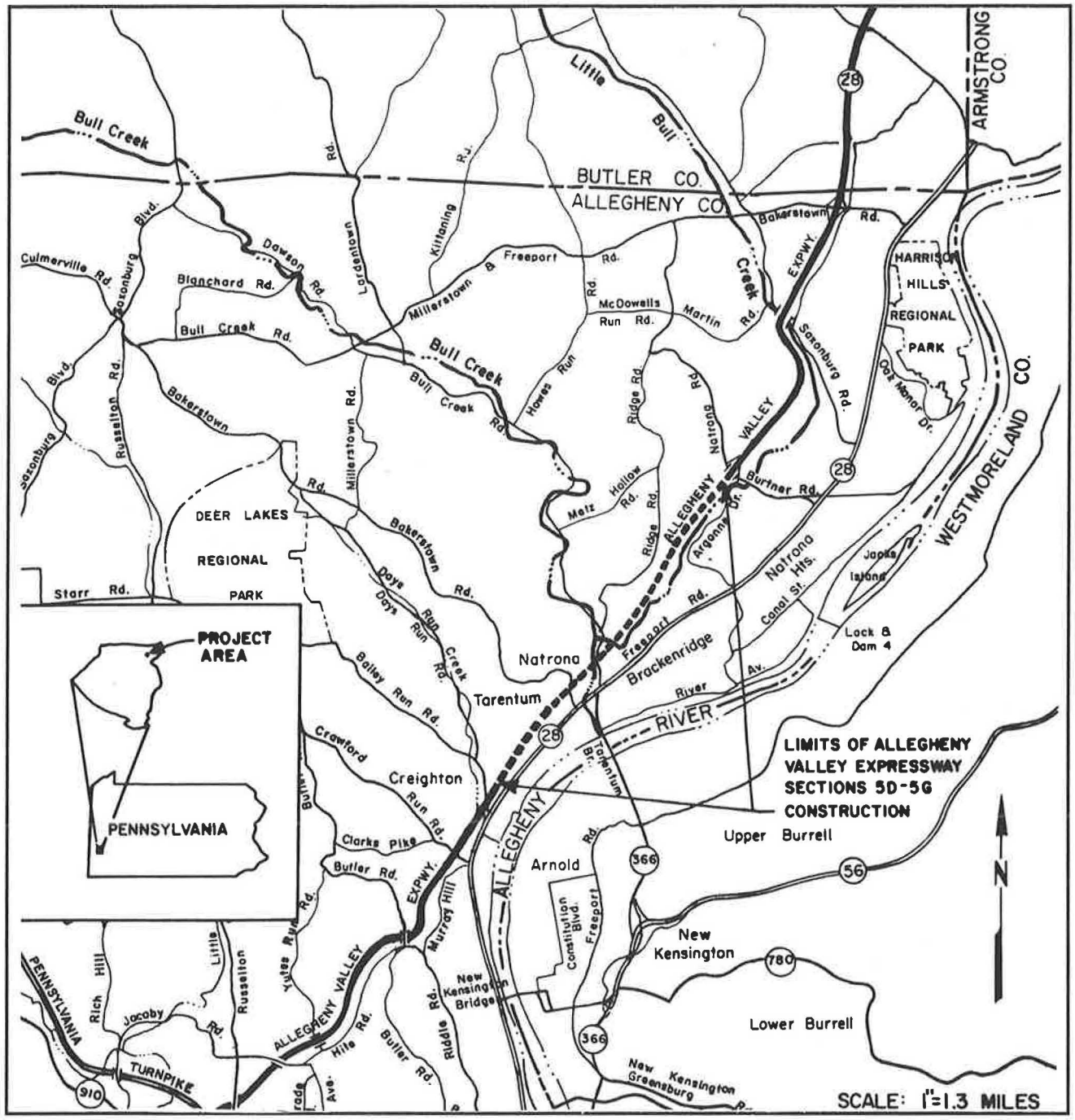


FIGURE 2 Project location map.

The original design for each of the sections included some mitigative design features for the stream relocations but no mitigative features for the construction of the large arch culverts. The primary goal of the original design appeared to be the safe passage of flood waters.

During the agency and public review of the draft EIS for the final sections of the expressway, the state and federal resource agencies strongly objected to the adverse impacts of the proposed design on the biological communities in Bull Creek and Little Bull Creek. In addressing the agency concerns, PennDOT and FHWA worked closely with the resource agencies to revise the project design and to incorporate measures to mitigate the adverse impacts on these streams. However, during this effort, all those involved realized that little information existed on which to base the revised stream relocation, mitigation, and culvert designs.

As a cooperative effort to fill this information gap, PennDOT and FHWA implemented Research Project 79-10, which was completed in 1983 *(2)*. In this project the biological conditions in the two streams were documented before, during, and after the majority of the stream relocations and the culvert construction, which made up Sections 5D and 5E of the four last stages of construction of the expressway. Following completion of the remaining two sections (5F and 5G) in 1985, PennDOT

and FHWA initiated Research Project 84-31 to comprehensively document the construction effects of all the last construction sections on the stream biological communities, with special emphasis on the cost-effectiveness of the mitigative design features.

RESEARCH OBJECTIVES

The objectives of the research project were to

1. Identify and describe any biological impacts of the construction project within the Bull Creek and Little Bull Creek watersheds.
2. Determine the effectiveness of the mitigative design features that were incorporated into the culverts and relocated stream channels to prevent or minimize adverse biological impacts.
3. Compare costs of the project as built with its costs if mitigative design features were not incorporated.
4. Produce a report and slide presentation that would encourage highway designers and environmental professionals to incorporate mitigative design features into similar projects.

MITIGATION DEVELOPMENT AND DESIGN

The overall mitigation plan for Bull Creek and Little Bull Creek and the design of mitigation features evolved through a coordination process involving the department and the resource agencies. It is apparent that this coordination was undoubtedly a product of the EIS process. In retrospect, if the EIS had not been required, the original project design, which did not include these mitigation measures, would probably have been used for construction. The resource agencies involved in the mitigation design and waterway permit process included the Pennsylvania Department of Environmental Resources, the U.S. Environmental Protection Agency, the U.S. Army Corps of Engineers, the USDA Soil Conservation Service, the Pennsylvania Fish Commission, the Pennsylvania Game Commission, and the U.S. Fish and Wildlife Service.

It is important to note that the EIS also resulted in the consideration of highway location and structure alternatives to completely avoid the impacts of the stream relocations and culvert construction. During the development of the final EIS and efforts to resolve the agency concerns, PennDOT and FHWA demonstrated through additional engineering and environmental studies that it was in the best public interest to relocate the streams and construct the culverts. However, the designs for this construction were to include adequate mitigative measures to minimize adverse impacts on the streams.

The coordination that ensued during the circulation of the draft EIS and preparation of the final EIS continued throughout the final design and construction of the project. Four mitigation goals were agreed upon early in the coordination process and served throughout the development of the project:

1. The highway and interchange were to be built so as to ensure the maintenance of the present and future potential of the Bull Creek watercourse to support aquatic life, which is beneficial and necessary to the creek's use as a fishery resource.

FIGURE 3 Bull Creek Road Interchange of the Allegheny Valley Expressway.

Therefore, modifications to the existing watercourse were not to inhibit the migration and habitation of fish and aquatic flora and fauna. Figure 3 shows the Bull Creek Road Interchange, under which Bull Creek and Little Bull Creek pass in arch culverts.

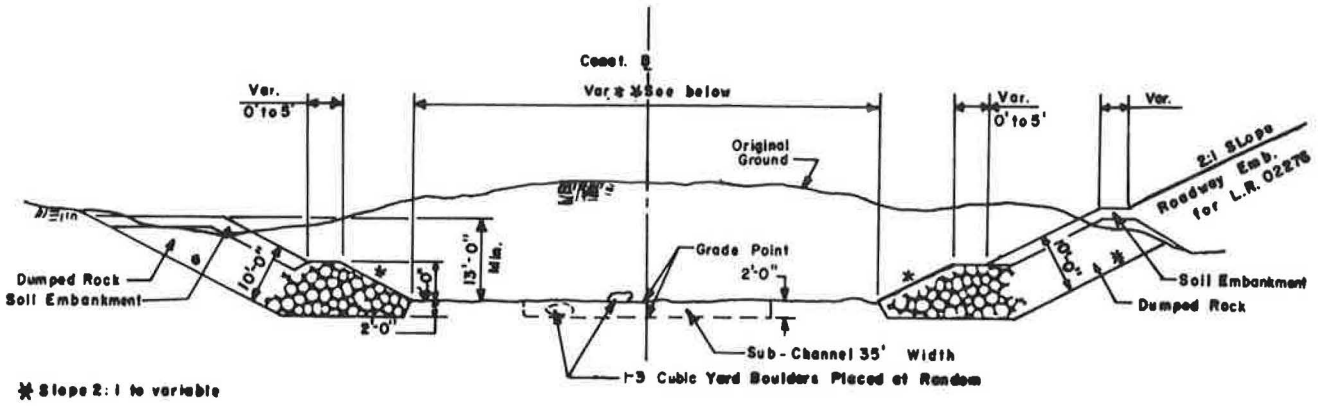
2. The department was to take whatever action was necessary to promote development of a recreational fishery within the relocated stream channels.
3. Habitats for game and non-game species were to be provided along the relocated streambank.
4. The relocated stream channel for Bull Creek and arch culverts for Bull and Little Bull creeks were to provide for adequate passage of the 50-year frequency flood, as required by U.S. Army Corps of Engineers.

In order to achieve the four mitigation goals for Bull Creek and Little Bull Creek, mitigative design features were incorporated into the channel relocations and culvert construction as follows.

Bull Creek

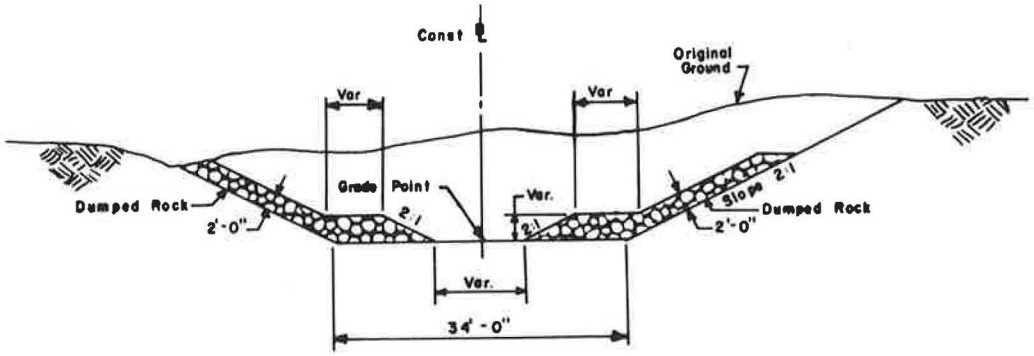
Relocated Channel

1. The gradient and length of the original stream channel were maintained as much as possible.
2. The new stream channel was constructed in the dry and stabilized with bottom and bank stabilization measures. The channel bottom was excavated into bedrock. The banks within the normal flow channel were lined with dumped rock, seeded, and mulched. The banks above the normal flow channel were either planted with shrubs and mulched with wood chips from the clearing and grubbing operations or planted with a legume-grass mixture and mulched with straw. Figure 4 shows typical sections of the relocated channel.
3. An uneven natural bottom was excavated.
4. Streambanks were lined with dumped rock in the normal flow channel. Above the normal flow channel, they were lined with rock, covered with soil, and planted.
5. A meandering subchannel was incorporated into the main channel with the use of deflectors constructed of gabions and logs and an elevated floodplain of dumped rock. Figure 5 shows a plan view of these and other mitigation features.
6. Large boulders were randomly placed in the subchannel.



TYPICAL CHANNEL SECTION – BULL CREEK

** Sta. 36+00 to Sta. 45+00 – 60'-0"
Sta. 45+00 to Sta. 45+50 – Var. 60'-0" to 70'-0"
Sta. 45+50 to Sta. 62+60 – 70'-0" (Inc. 35'-0" wide Sub-Channel)
Sta. 62+60 to Sta. 64+60 – Var. 70'-0" to 35'-0"
Sta. 73+45 to Sta. 87+50 – 35'-0"



TYPICAL CHANNEL SECTION LITTLE BULL CREEK

** Sta. 90+50 to Sta. 92+00 – No low flow Channel
Sta. 92+00 to Sta. 92+78.92 – Low flow Channel Slopes 2:1
Sta. 97+28.59 to Sta. 97+75 – Low flow Channel Slopes 1½:1

NOT TO SCALE

FIGURE 4 Typical channel sections of relocated Bull and Little Bull creeks.

7. Special grass and legume mixtures, shrub clusters, and trees were planted above the flood channel to provide wildlife habitat.

Arch Culvert

1. A bottom gradient of 2 ft per 1,000 was constructed to produce stream-flow velocities that would permit fish movement upstream under most flow conditions. Figures 6 and 7 show a cross section of the culvert.
2. A low-flow fish channel was constructed in the concrete bottom to permit fish passage during periods of low flow.
3. Dams and half dams were constructed every 50 ft to provide resting places in low-velocity pockets. Between the dams, rock fill was placed to provide bottom substrate.

Little Bull Creek

Relocated Channel

The channel was constructed similar to the Bull Creek channel except that the streambanks and stream bottom were lined with either gabion mattresses or riprap to provide erosion protection.

Arch Culvert

1. A bottom gradient of 12.9 ft per 1,000 was constructed to produce stream-flow velocities that would permit fish movement upstream under most flow conditions. Figure 8 shows a plan view of the mitigation features in the culvert.
2. A natural earth bottom was excavated and backfilled with rock to prevent scouring and provide bottom substrate.

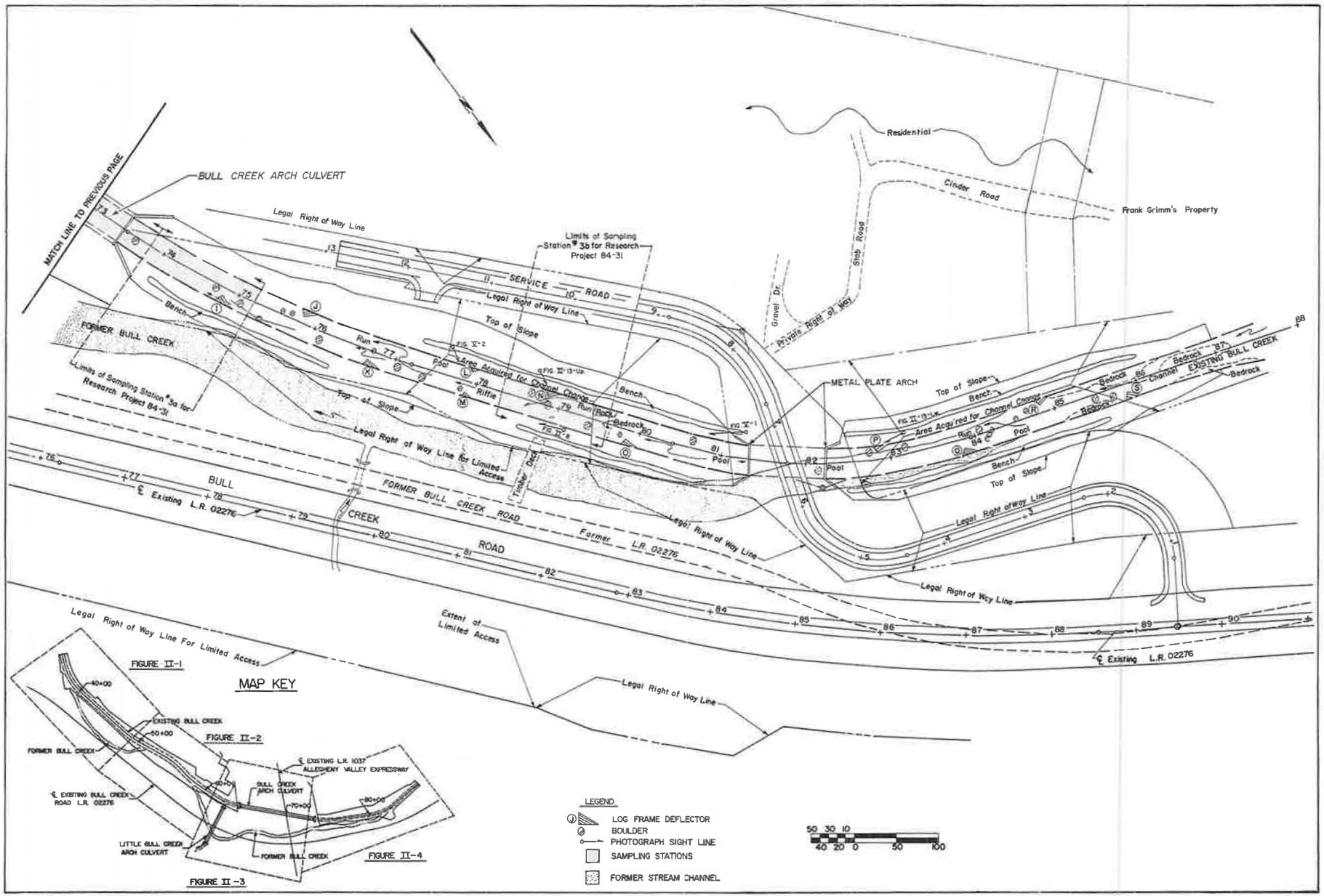


FIGURE 5 Mitigation features for channel relocation of Bull Creek.

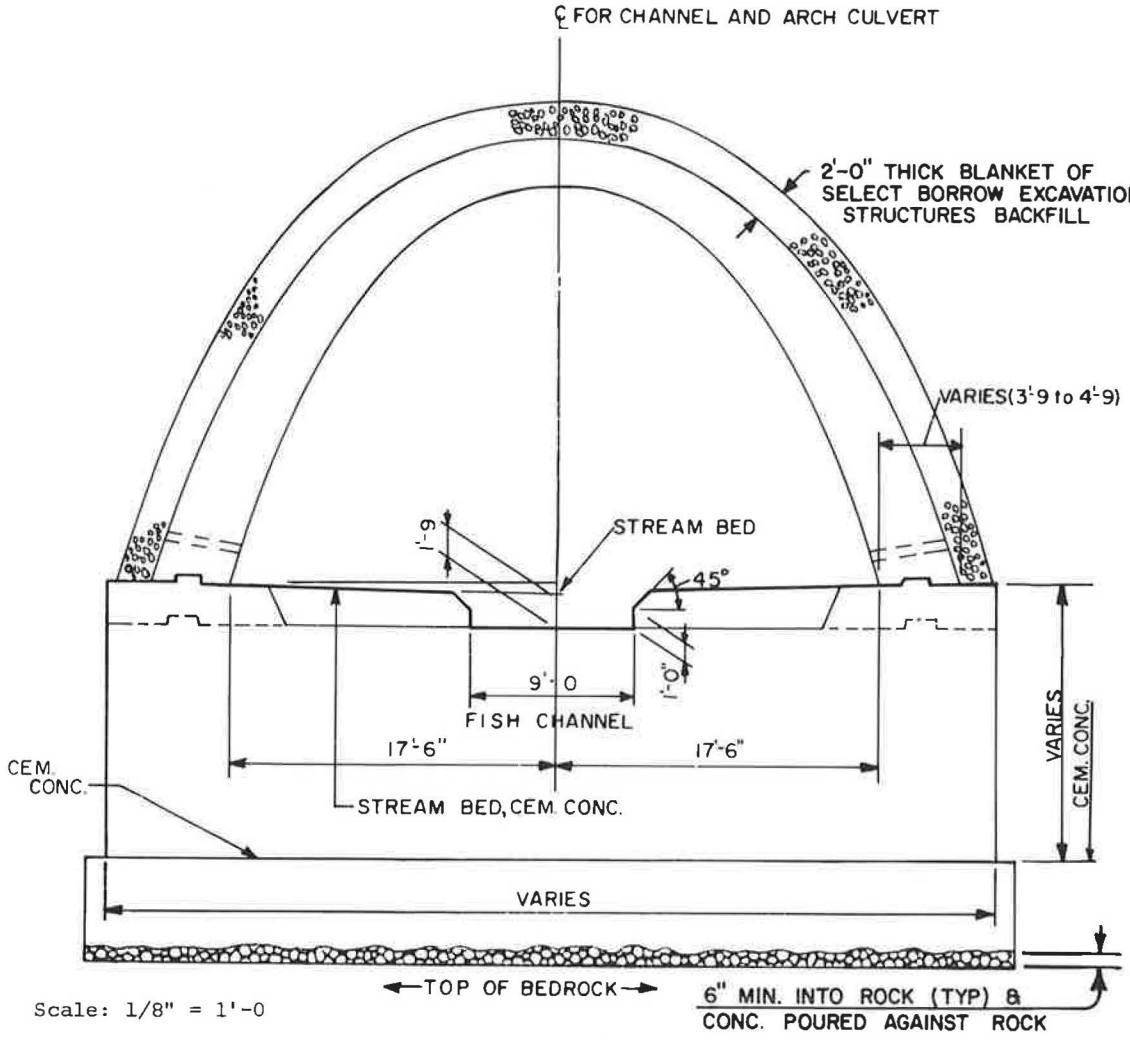


FIGURE 6 Cross section of Bull Creek arch culvert.

3. Five reinforced-concrete dams spaced at 75-ft intervals were constructed to provide resting places in low-velocity pockets. Low-flow notches were constructed in the dams to constrict flow and allow fish passage during a 7-day duration, 10-year frequency low flow.

4. Immediately downstream of each dam, pockets were left in rock riprap to provide resting places. Figure 9 shows the downstream end of the culvert.

In addition to the mitigative design features incorporated into the stream channels and culverts, special erosion and sedimentation control measures were implemented during construction. Examples of these measures include

- Constructing stream relocations and culverts in the dry,
- Maintaining natural vegetative buffers and straw bale barriers adjacent to streams,
- Constructing temporary pipe causeways and prohibiting stream fordings,
- Seeding and mulching soil stockpiles and graded areas that will lie dormant for extended periods,
- Directing flow from foundation dewatering operations and other disturbed areas into a series of sedimentation ponds, and
- Chipping all cleared vegetation and using chips for mulching banks with shrub cluster plantings.

MITIGATION COSTS

The total cost for the construction of the final link of the expressway was $44.9 million. The construction cost for the mitigation for Bull Creek and Little Bull Creek was about 4 percent of the total cost, or $1,849,650. Table 1 summarizes the costs for all the mitigation measures for Bull Creek and Little Bull Creek.

The original design for this final link of the expressway included a concrete-paved trapezoidal channel to carry the relocated Bull Creek, at an estimated cost of $1,750,000. In comparison, the mitigated channel for Bull Creek was constructed for $1,714,000.

As discussed earlier, the resource agencies requested that a bridge structure over Bull Creek be investigated as an alternative. As part of this investigation PennDOT performed a cost analysis comparing the construction costs of the structure alternative with the design utilizing arch culverts and fill embankment. The construction cost of the structure alternative was 15 percent higher than that of the arch culvert design. Also, the

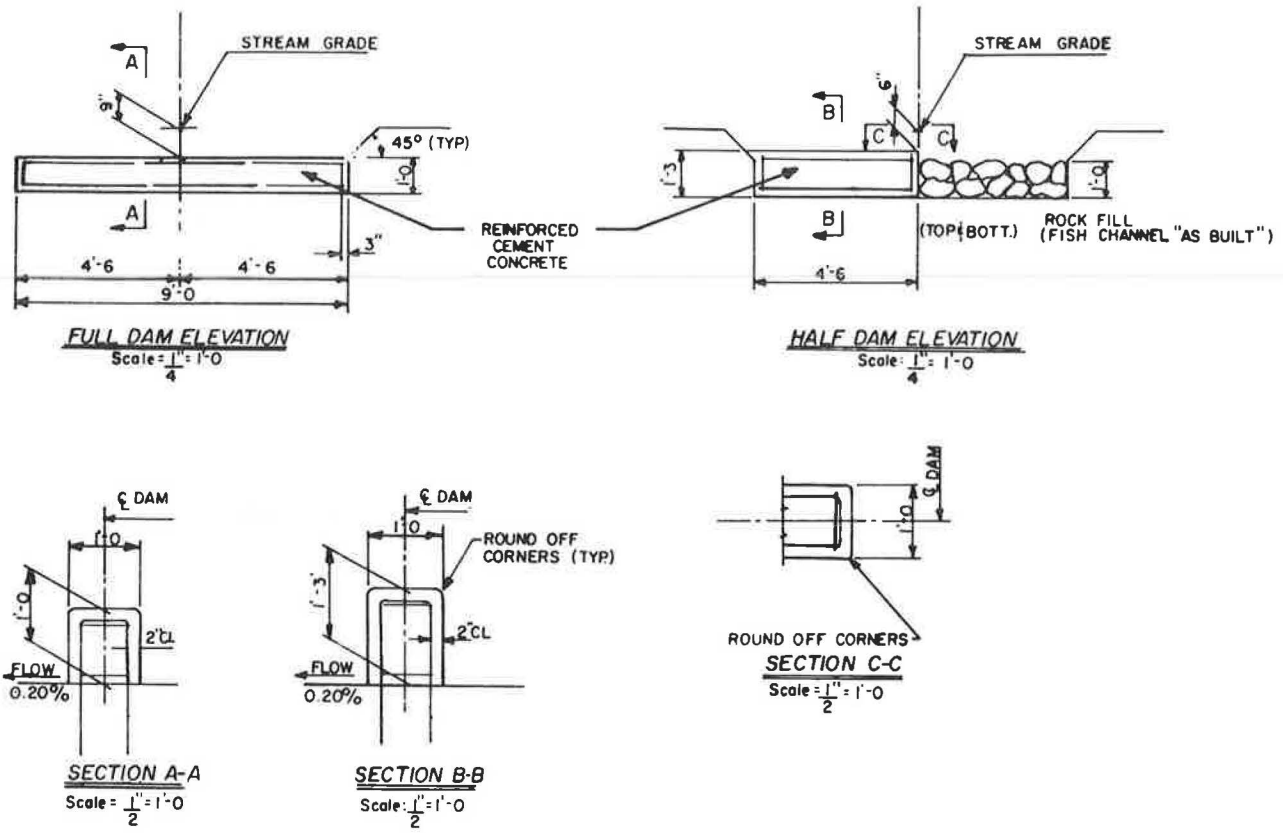


FIGURE 7 Fish channel dams in Bull Creek arch culvert.

redesign effort required to convert to a bridge structure alternative would have caused substantial project delays and would not have significantly reduced the amount of relocation required for Bull Creek. After reviewing the results of the alternatives analysis, the resource agencies agreed to the arch culverts if adequate mitigative features were incorporated.

MITIGATION EFFECTIVENESS

An important part of determining the effectiveness of the mitigation measures was an evaluation of the fish and macroinvertebrate communities and their habitat, the relocated channels and culverts.

Research Project 79-10 *(2)* described the biological conditions and water quality in Bull Creek and Little Bull Creek immediately before, during, and after construction of Sections 5D and 5E of the expressway. Most of the channel relocation and culvert construction on Bull Creek and the lower reaches of Little Bull Creek was completed as part of Sections 5D and 5E.

Research Project 84-31 *(1)* reassessed the biological and physical conditions and water quality in Bull Creek and Little Bull Creek after construction of Sections 5F and 5G, which completed the expressway. Two channel relocations in the middle and upper reaches of Little Bull Creek in the project area were the only direct stream involvements with these sections. Equivalent sampling and analysis methods were used for both research projects.

The major components of the Research Project 84-31 biological study were

1. Description of physical habitat,
2. Measurement of water quality,
3. Characterization of resident fish and macroinvertebrate communities,
4. Assessment of success with streambank planting,
5. Incidental wildlife observations, and
6. Comparison with Research Project 79-10 data.

Eight sampling stations were utilized for both research projects. Control stations upstream and downstream of the expressway construction area were sampled. Some stations were moved to adjacent areas when necessary because of construction.

The physical condition and function of the mitigation features were evaluated in June, July, and August 1985, approximately 4 years after most of them had been installed. The observations were made in what was considered to be the normal to low stream flow conditions during which the mitigation features would be expected to function throughout most of the year. In addition, the physical effects of a major storm event in July 1985 were evaluated.

By analyzing and comparing the results of the biological and physical studies of both research projects, the effectiveness of the mitigation was assessed in view of the mitigation goals established early in the design process.

In summary, the assessment of the mitigation effectiveness showed that overall, all of the mitigation goals were met as follows:

- The affected portions of Bull Creek include varied stream width, water depth, flow velocity, and meandering subchannel, which do not inhibit the migration and habitation of fish and associated aquatic flora and fauna.
- A diversity of aquatic habitat types are present in both streams, including riffles, runs, pools, and scour holes, which are in similar or better than preconstruction conditions.
- Postconstruction populations of fish species throughout Bull Creek are as high as or higher than before construction.
- Numbers, identity, and importance of macroinvertebrates in relocated reaches were generally as good as or better than before construction. Benthos in the Little Bull Creek culvert were generally similar to those in the relocated stream reaches, whereas those in the Bull Creek culvert were degraded compared with those in downstream reaches.
- Both the presence of sport fishes such as largemouth bass, smallmouth bass, and brown trout and frequent observations of anglers fishing in the relocated portions of Bull Creek and

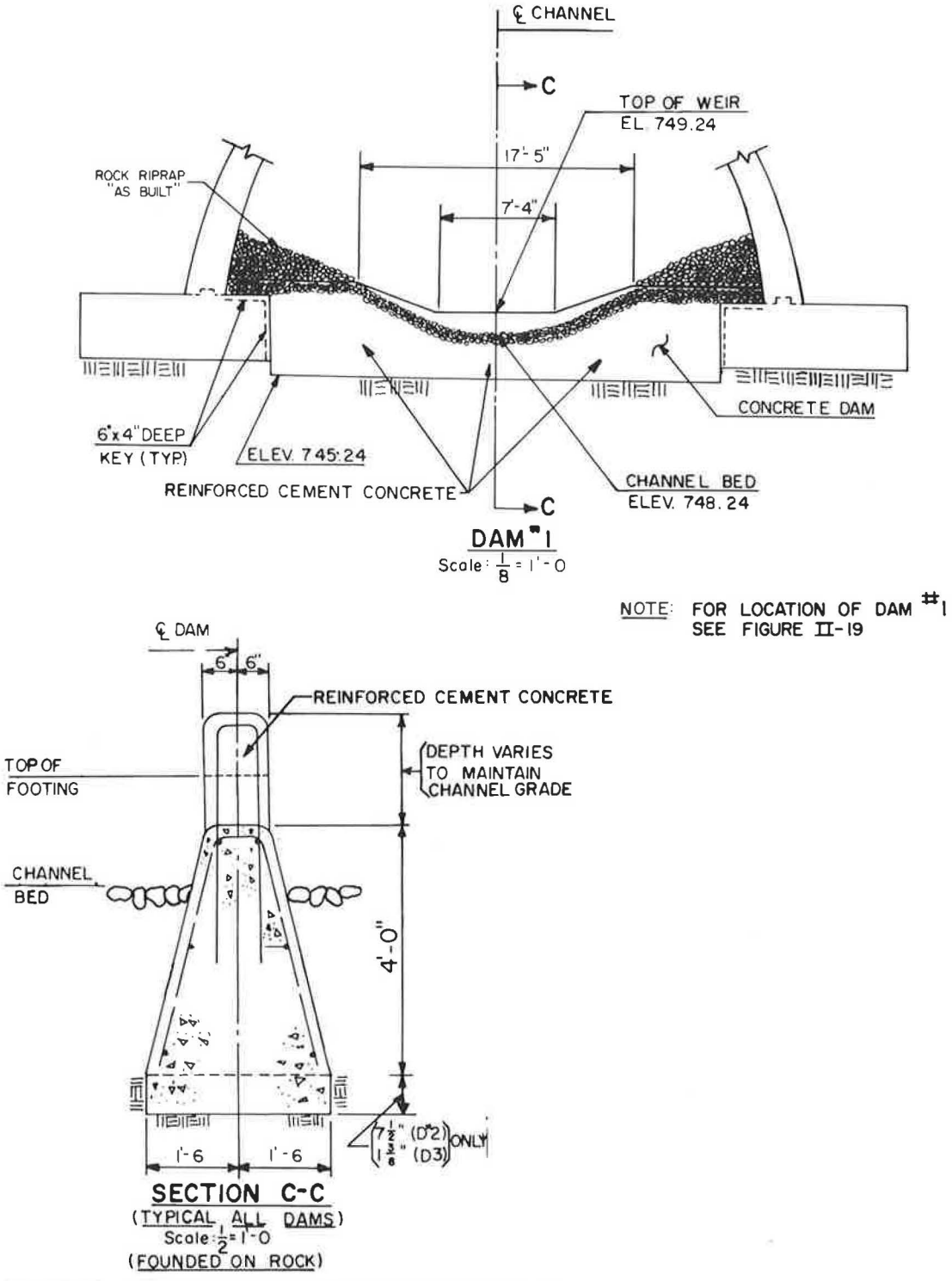


FIGURE 8 Mitigation features in Little Bull Creek arch culvert.

TABLE 1 MITIGATION COSTS FOR BULL CREEK AND LITTLE BULL CREEK

MITIGATION MEASURE	DESCRIPTION	QUANTITY	UNIT COST	TOTAL COST[a]
BULL CREEK				
Log-Frame Deflectors	Type A	6	$ 3,200 ea.	$19,200
	Type B	11	$ 2,800 ea.	30,800
	Type C	2	$ 2,400 ea.	4,800
				$54,800
Gabion Deflectors	Avg. 106' long 3'-3" wide 3'-3" high	9 (1,039 cy.[b])	$13,850 ea. ($120/cy.)	$124,680
Channel Treatment Boulders	1-3 cy. ea.	50 Boulders	$120 ea.	$6,000
Select Rock Borrow Excavation - Bull Creek Channel Lining	12" minimum dimension	84,120 cy.	$17/cy.	$1,430,040
Rock Fill - Fish Channel	4" minimum dimension	289 cy.	$85/cy.	$24,565
Select Rock Borrow Excavation - Little Bull Creek Channel lining near arch culvert	12" minimum dimension	1,766 cy.	$19/cy.	$33,554
Bull Creek Arch Culvert	fish channel dams	17	$235 ea.	$4,000
Little Bull Creek Arch Culvert	fish dams	5	$3,375 ea.	$16,875
Supplemental Streambank Plantings	native shrubs	9,280 one year bare rooted cuttings $2 ea. 3,521 sy[b] direct seeding of two herbaceous seed mixtures $.30-$.35/sy		$19,694
		TOTAL COST		$1,714,208
LITTLE BULL CREEK				
Gabion Mattress Stream Channel Paving	12'x6'x9"	1,290 cy.	$105/cy.	$135,450[c]
Channel Treatment Boulders	1-3 cy. ea.	25 Boulders -0-[d]		-0-

[a] Costs were adjusted to 1981 dollars.
[b] cy. = cubic yard and sy. = square yard.
[c] These costs are presented in 1984 dollars.
[d] Contractor placed boulders at no charge.

the culvert indicate that a recreational fishery has developed. This is also demonstrated by the recent addition of a 1.8-mi portion of Bull Creek, including the relocated section, to the 1986 trout-stocking list of the Pennsylvania Fish Commission. Although a creel survey has not been conducted, observations made during the opening day of the 1986 trout season showed several fisherman with trout they had caught in this area.

- Good to excellent survival rates of streambank plantings and aggressive colonization by native plant species provide a wildlife habitat for several species observed during the field work. Figure 10 shows the streambank vegetation.
- As shown by the safe passage of flood flows from a July 1985 storm event that approached or exceeded the 50-year frequency, the relocated streams and culverts are hydraulically adequate.

RECOMMENDATIONS

On the basis of the experience and knowledge gained during these research projects and the expressway's construction, several recommendations were made by the research team for planning, designing, constructing, and maintaining mitigative features for stream relocations.

Planning Stage

1. Thoroughly investigate the physical, hydrological, chemical, and biological characteristics of the stream to be affected.
2. Coordinate with the environmental regulatory and review agencies as early as possible in the planning process. Ideally,

FIGURE 9 Downstream end of Little Bull Creek arch culvert.

the resource agencies should be involved in development of alternatives. Also, conduct field views throughout the development of the project to show the agencies how the mitigation measures are constructed and how they are working.

3. Determine whether relocation can reasonably be avoided or, if not, whether mitigation will be applicable on the basis of water or fishery resource values.

4. Define specific goals and objectives for mitigation in terms of both physical and biological parameters and time frames. Specify how and when mitigation success will be measured.

5. Plan for enhancement or improvement of the resource where possible.

Design Stage

1. Design mitigation devices such as log frame and gabion deflectors to withstand the anticipated variations in streamflow velocities under flood conditions.

2. Where flood flow passage within the channel is a primary objective, specify in-stream mitigation devices such as gabion deflectors, which do not greatly inhibit flow passage.

3. Where a relatively wide channel is required to pass flood flows, provide a subchannel defined by deflectors for low-flow fish habitat diversity.

4. Use boulders in the stream channel large enough to resist movement (1 to 3 yd^3 depending on stream characteristics) to provide cost-effective stream habitat diversity.

5. Use log frame deflectors, properly anchored, to create channel narrowing and deepening at specific locations.

6. Use gabion deflectors to create subchannel meanders and depositional floodplain areas within the main channel.

7. Plan changes in stream channel gradient carefully to avoid unwanted zones of siltation and sedimentation.

8. In "flashy" flow streams, design deflectors and other in-stream devices to accommodate large variability in discharge rates, but design them to function at normal or median flows.

9. Avoid gabion mattress channel bottom and streambank paving where fish and wildlife mitigation is a primary consideration.

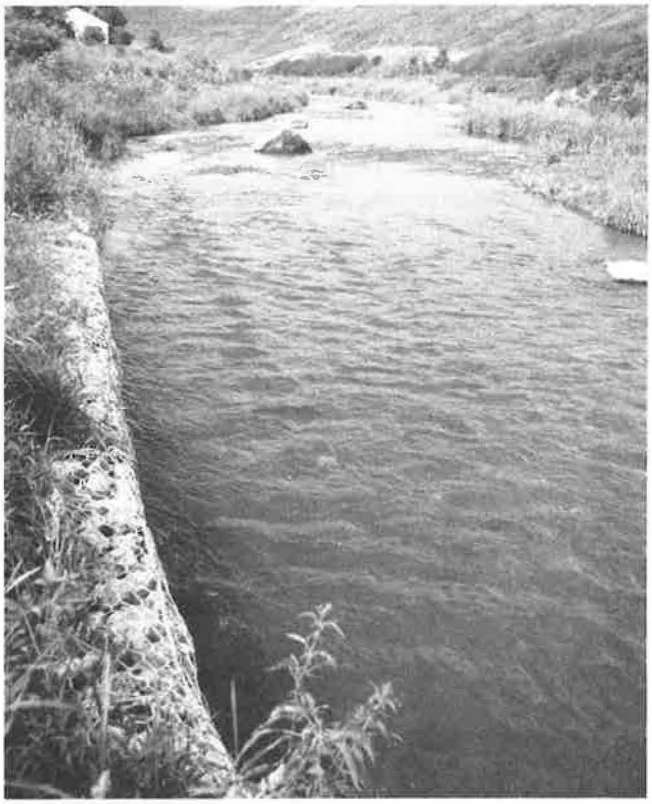


FIGURE 10 Streambank vegetation.

10. Include in planting plans native shrubs and trees located as close to the stream as flood passage considerations will permit.

11. Specify bare-rooted cuttings of native shrubs to maximize survival.

12. Where long culverts are to be utilized, consider the following design recommendations:

a. Address design and implementation of fish passage through culverts on a case-by-case basis.

b. Consider the following physical attributes of the stream in culvert design: stream gradient, substrate, sediment load, and flood and low-flow characteristics.

c. In planning for fish movement or migration through culverts, consider the streamflow regimes at the time of year when migration normally occurs. Where general fish movement is the prime consideration, consider various streamflow regimes.

d. Design through-culvert flow velocities and fish movement aids to suit particular target fish species. Design for a flow velocity in the culvert that will allow upstream fish movement based on empirical studies.

e. Design the culvert so that large variations in stream discharge produce only small changes in flow velocity through the culvert.

f. If a low-flow fish channel is to be used inside the culvert, provide for low-velocity resting areas by including dams and half-dams. Line the bottom of the fish channel with rock to approximate natural stream bottom conditions, but do not fill it.

g. If heavy siltation is a persistent problem in the impacted stream, do not provide a low-flow channel; let it develop naturally within the culvert.

h. Depress the culvert invert grade line below normal stream-bed level to encourage pool formation in the culvert where possible.

13. Use design experts knowledgeable and experienced in fish and wildlife mitigation techniques.

14. To the extent practicable, utilize other streambank protective measures (e.g., live stakes) in lieu of riprap.

Construction Stage

1. Consider placing mitigation devices in relocated channels after establishment of streamflow to assist in setting proper elevations.

2. Selectively place large rocks along the leading edge of log frame deflectors to break up current velocity and protect the devices from undercutting.

3. Use riprap rock to protect the upstream ends of gabion deflectors from washout or creation of channel behind the gabion. Also key the upstream end of gabion deflectors into streambanks where washout protection is necessary.

4. Generally avoid placement of deflectors in the stream channel where bedrock is exposed. The rock will generally provide adequate channel bottom roughness and habitat diversity.

5. Ensure that plantings are carried out within specified dates to maximize survival.

6. Follow specified planting sequence to minimize construction damage and have the construction inspector consult with the professionals knowledgeable in habitat planting design.

7. Remove stakes and guy wires from planted material after plants are well established (longer than 2 years).

Postconstruction Maintenance

1. Provide inspection of stream mitigation measures on a periodic basis and after all major precipitation events.

2. Perform maintenance such as debris removal, gabion repair, or major erosion repair as necessary to ensure stream-bank and channel protection.

3. Avoid in-stream maintenance where possible after reestablishment of the stream ecosystem.

ACKNOWLEDGMENT

Special thanks to the panel members who guided these research efforts and the research team who professionally performed the research. The principal researchers were John Wakelee and Derek Piper of Skelly and Loy, Engineers-Consultants; and Robert Blye, William Ettinger, and Douglass Nieman of RMC Environmental Services.

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Publication of this paper sponsored by Committee on Landscape and Environmental Design.