6. The study was the first Minnesota DOT scoping process that allowed for early elimination of route alternatives and recommended a manageable number of alternatives for the EIS process, thus shortening the EIS process considerably.

The Minnesota DOT was impressed with the scoping technique used in the study, which provided data for decision making in a comprehensive and efficient manner. The phase 2 report was a landmark accomplishment for the Minnesota DOT. The project represents an integration of the computer mapping technique into the transportation planning process.

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Controlling Acidic-Toxic Metal Leachates from Southern Appalachian Construction Slopes: Mitigating Stream Damage

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Highway construction activities in the southern Appalachian Mountains have exposed geological formations that contain pyritic materials (Anakeesta formation), and drainage from slope and fill has caused considerable change in streams that receive these toxic leachates. These drainages, which mobilize high levels of free acidity (low pH) and various toxic metals (aluminum, copper, iron, manganese, and zinc), have destroyed aquatic ecological systems in reaches of mountain streams of the Great Smoky Mountains National Park and tributaries of Citico River and Tellico River drainages in the Cherokee National Forest. In the North River drainage of the Tellico River, mitigation procedures were initiated in 1977 by FHWA to seal exposed Anakeesta road fill of the Tellico-Robbinsville Highway with soil blankets and temporary sodium hydroxide (NaOH) neutralization. A study conducted to evaluate the effectiveness of the controlling technologies used in meeting water-quality objectives is described. Assays of fish population, in-stream fish bioassays, and water-quality assessments were carried out in the watershed during 1978-1979. Initial improvements in stream water quality and biological accommodations occurred in mitigated streams during NaOH treatments and soil blanket installations. However, survivability tests and fish surveys revealed that rainbow trout could not survive in acid streams 6 months after the soil blankets had been installed. Depressed pH and elevated metal concentrations contributed to fish mortalities in these streams.

The scenic Tellico-Robbinsville Highway traverses ridges and peaks of the southern Appalachian Mountains from Tellico Plains, Tennessee, to Santeetlah Gap in the Nantahala National Forest in North Carolina. In 1977 acid drainage originating from recently constructed road-fill areas was contaminating nearby trout streams in the Cherokee National Forest (1). Highly mineralized rock material in the highway embankments was producing acid-toxic metal leachates. Deleterious effects on aquatic biota occurred in McNabb and Hemlock Creeks of the North River watershed and Grassy Branch of the Citico Creek drainage, which were draining the acidic road fill. This problem caused much concern because these streams lie within the Tellico Wildlife Management Area, which is known for its good trout fishing. Furthermore, much of the region had been designated as a potential wilderness area (2).

In early 1978 FHWA began efforts to mitigate the acid drainage problems. The objective of this study was to evaluate the immediate and short-term effectiveness of these measures on aquatic life in the acid-leachate-mitigated streams. In meeting this objective, assays of fish population and in-stream toxicity and water-quality assessments were carried out from April 1978 to July 1979 in the North River drainage basin.

BACKGROUND

Highway construction between Tellico Plains, Tennessee, and Robbinsville, North Carolina, began in 1965. More than a decade later, in 1977, acid drainage from completed sections of the Tellico-Robbinsville Highway altered water quality and reduced the abundance of trout in the adjoining North River and Citico Creek watersheds (1). These watersheds lie within the Tellico Wildlife Management Area, where streams have typically been soft water--slightly acidic drainages supporting an excellent sport fishery of stocked and native trout species. The headwaters of streams affected by Anakeesta leachates--McNabb Creek, Hemlock Creek, and Grassy Branch Creek--are adjacent to highway embankments. These streams exhibited depressed pH values, increased concentrations of sulfates, heavy (toxic) metals, and acidity. Highway embankments containing sulfide-rich pyritic units of the Anakeesta formation were believed to be the sources of acid drainage (1,3).

Neutralization of acid leachates in receiving streams was begun in May 1978 and continued through January 1979. An interim mitigation measure of sodium hydroxide (NaOH) additions was used. A 20 percent solution of NaOH was gravity-metered into the headwaters of affected streams in an attempt to maintain a pH level of approximately 5.8 at the mouths of these streams. Additional remedial actions taken to reduce leachate runoff included asphalt curbing, ditching, and surface drain installations. A lime slurry (approximately 60 tons/acre) was sprayed over selected embankments to reduce migration of acid salts into overlying soil layers to be installed during permanent abatement measures (1).

More permanent mitigation involved sealing exposed Anakeesta material in the road embankments from surface water infiltration. This decreased oxidation-acidification mechanisms and subsequent leachate production. After the addition of lime, approximately 0.6 m of topsoil was placed over exposed rock and seeded with grass. A fiberglass roving layer and then a coating of tar were used to cover the soil to help inhibit erosion. Silt barriers were also placed below soil-covered embankments to reduce inherent siltation problems. Permanent surface sealing of selected embankments was completed by December 1978 (1).

METHODS AND MATERIALS

Hemlock and McNabb Creeks in the North River watershed of the Tellico Wildlife Management Area were sampled for fish populations each quarter from April 1978 to July 1979 by using electrofishing techniques. In conjunction with this assessment, benthic macroinvertebrate communities were characterized monthly. Results of these assessments have been summarized elsewhere (4-6).

Thirty hatchery-reared rainbow trout (Salmo gairdneri) were used at each of 10 stations in 4-day, in-stream bioassays conducted simultaneously with fish population studies to evaluate the suitability of mitigated streams for sustaining fish life. Routine water-quality measurements were taken monthly on site at 13 stations during biological and physical-chemical assessments, and water samples collected from each were placed on ice and returned to the laboratory for more detailed analysis (7). Metal concentrations were analyzed by using atomic absorption spectrophotometry.

RESULTS AND DISCUSSION

Studies of water quality and fish populations and in-stream fish bioassays were carried out from April 29, 1978, through July 1, 1979, to evaluate the effectiveness of acid drainage abatement measures in mitigated streams. The results were separated into three sampling phases:

1. April 28 through May 6, 1978, the period before mitigation efforts by FHWA;
2. June through December 1978, designated the mitigation period, during which acid-receiving streams were affected by both NaOH additions and soil blanket construction over exposed Anakeesta road-fill materials within stream watersheds; and
3. January through July 1979, designated the postmitigation period (installation of road-fill soil blankets and termination of NaOH treatments had been completed before the beginning of this final phase of study).

It should be emphasized that the designations "mitigation period" and "postmitigation period" were chosen for the sake of clarity in discussion. Because installations of soil blankets over exposed Anakeesta road-fill materials were considered permanent measures, there was no definitive period of mitigation.

WATER-QUALITY ANALYSIS

Physicochemical water-quality measurements were taken on April 29 and May 6, 1978, at 13 North River sampling stations before acid mitigation measures began. The results were similar to results obtained by FHWA (1), given in Table 1: depressed pH and alkalinity and increased water hardness and conductivity levels occurred in Anakeesta leachate-receiving streams. The pH varied from 4.0 to 4.8 in McNabb and Hemlock Creeks, from 5.0 to 5.4 in North River below these streams, and from 5.5 to 6.7 at upstream reference stations. The highest acidity values were recorded at affected stream stations, but acidity values were variable; the Sugar Cove reference site (station 1) showed higher acidity (31.3 mg/L as $CaCO_3$) than stations 8, 10, and 11 (22.0 to 22.8 mg/L as $CaCO_3$) in McNabb and Hemlock Creeks. The ranges of dissolved oxygen levels (9.4 to 9.9 ppm) and water temperatures (10.5° to 11.0°C) in acid-receiving streams were comparable to those for reference stations.

Analyses indicated that the water quality of streams that received acid drainage was altered as far downstream as station 13 on the North River, just before its confluence with the Tellico River. This station was located approximately 5.4 and 7.4 km downstream from the two sources of Anakeesta leachates at the headwaters of Hemlock and McNabb Creeks. Water-quality conditions in the North River drainage during the fall of 1977 indicate that these streams were being affected as far downstream as the Tellico River, immediately below the North River (1).

Herricks and Cairns (8) state that the capacity of a stream or river to assimilate acid mine drainage (similar to the highway acid drainage in the study) depends on several factors, most important of which are stream flow (dilution capacity) and total alkalinity (neutralization capacity). In addition to the amount and mineralogical composition of exposed Anakeesta in the highway embankments, the intensity of the acid stress found in McNabb and Hemlock Creeks might be attributed to a very limited buffering capacity in these streams. North River streams typically have low alkalinity, often less than 5 mg/L as $CaCO_3$.

Dilution of the acid Anakeesta drainages in the North River was thought to be the primary factor affecting the concentration of the leachate materials below McNabb and Hemlock Creeks. Maas (9) states that the primary mechanism of recovery from Anakeesta pyrite-related stream contamination is dilution by unaffected side streams and groundwater. Poorer water quality occurred at station 12 (which was affected by both McNabb and Hemlock Creeks) than at upstream station 9, which was immediately below McNabb. Some improvement in water quality was observed several kilometers downstream at station 13 in the North River.

Although dilution and neutralization mechanisms undoubtedly play important roles in regulating concentrations of leachate materials, on the Tellico River flow was observed to be an important regulating factor in mobilizing aluminum. Specifically, as the kinetic energy was reduced in the flow at or near the isoelectric pH, aluminum complexes precipitated as thick, whitish blankets covering stream substrates.

Mitigation Period

Water samples were collected at 13 stream stations from July through December 1978 during NaOH treatments and soil blanket installations over exposed Anakeesta road-fill areas. Improved water quality at McNabb Creek sampling stations was reflected in pH values, which ranged from 6.0 to 7.2 during additions of NaOH. These pH levels were comparable to reference stream values. A reasonable improvement was seen at Hemlock Creek sampling sites, which exhibited pH values between 5.5 and 6.7. However, a

Table 1. Premitigation summary of FHWA water-quality analyses at 14 stream sampling sites from August 15 through October 14, 1977.

		Acidity, Alkalinity, and Hardness (mg/L as $CaCO_3$)				Metals (mg/L)			
Sampling Size	pH	Acidity to pH 8.3	Total Alkalinity	Total Hardness	Conductivity (μmhos/cm)	Sulfate	Aluminum	Manganese	Iron
McNabb									
Headwater	3.7	386.0	0.2	728.0	1353	1070.0	64.00	34.80	2.69
Upstream	4.1	68.5	0.2	128.0	380	194.0	11.00	12.00	0.04
Station 8	4.7	24.4	0.2	56.6	305	75.0	3.50	1.95	0.04
Station 7	4.7	18.6	0.2	47.2	140	62.0	2.52	1.62	0.01
Hemlock									
Headwater	3.9	82.0	0.0	–	1970	–	31.10[a]	8.50[a]	0.07[a]
Upstream	3.3	37.0	0.2	65.0	270	94.0	7.00	5.60	0.03
Station 11	3.4	29.4	0.2	54.6	257	98.0	7.00	1.98	0.10
Station 10	3.5	25.3	0.2	49.0	220	72.0	3.74	1.70	0.26
North River									
Station 6	6.3	2.8	8.6	8.6	24	2.0	0.33	0.01	0.18
Station 9	6.4	1.9	6.3	13.6	32	9.5	0.36	0.20	0.31
Station 12	6.1	1.9	5.2	16.5	41	14.1	0.33	0.26	0.17
Station 13	5.3	2.8	5.3	16.3	41	14.1	0.36	0.20	0.17
Tellico River									
Upstream	6.1	2.8	4.6	5.0	11	1.6	0.40	0.02	0.09
Downstream	5.9	4.2	5.0	11.8	24	9.3	0.33	0.13	0.19

[a]Values measured May 11, 1978.

paired t-test indicated that pH values at both stations 10 and 11 on Hemlock Creek were significantly lower ($p < 0.01$) than at all other stations except station 4 on Laurel Branch, a reference stream. Although mean pH at Laurel Branch was 0.1 to 0.3 pH units lower than mean pH values at other reference sites, no significant differences ($p < 0.01$) in pH were found between any of the reference stream stations.

Laurel Branch could possibly have been receiving low levels of Anakeesta leachates from the road cut that terminated several hundred meters into the watershed or from natural outcroppings of pyritic material that might occur in the drainage. However, the degree of acidity in Laurel Branch was minimal regardless of hydrogen ion sources, and the biological communities in this stream were characteristic of clean-water reference systems throughout the entire study period. The pH values in the North River below acid-mitigated streams were similar to pH values at upstream North River stations.

Longitudinal pH profiles taken in mitigated streams during NaOH treatments indicate that pH neutralization (pH to 7.0) did not occur before a point approximately 2 km downstream of the metering stations (3). Caustic pH values as high as 13 occurred immediately below treatment stations. Thus, improvements in water quality observed at downstream sampling stations were not expected in the headwaters of McNabb and Hemlock Creeks due to excessively high pH levels.

Total alkalinity values measured at the two Hemlock Creek sampling stations ranged from 0.1 to 7.0 mg/L as $CaCO_3$ during this period. Alkalinity values at these stream sites were significantly lower ($p < 0.01$) than at all other stream stations except station 4. At station 4 in Laurel Branch, alkalinity varied from 3.2 to 12.3 mg/L. These values were not statistically different from those at other reference stations, which ranged from 2.0 to 22.8 mg/L. Only minor differences were found between alkalinity levels for McNabb Creek and reference stream stations.

Acidity was variable at all North River sampling stations from September through December 1978, but the highest acidity values were frequently found at reference streams. Additions of NaOH from May through December 1978 probably reduced the level of acidity in receiving streams during these months by reacting with mineral salts and acids in solution.

Measurements of water hardness were also variable from July through December 1978. The highest values were typically found at mitigated stream stations during this period, particularly in Hemlock Creek, which exhibited the highest hardness levels. A peak level of 70 mg/L (as $CaCO_3$) was measured in Hemlock Creek in December 1978.

Conductivity (μmhos/cm) remained high at all mitigated stream stations, in comparison with reference streams, from May through December 1978, apparently as a result of NaOH neutralization measures. Conductivity (or specific conductance), which is a measure of the total amount of ionized materials in the water (10), is a sensitive indicator of Anakeesta leachate contamination in Tellico River streams (1). Conductivity levels generally decreased downstream as a function of increased stream flow and dilution in NaOH-treated streams.

The occurrence of dense precipitates was noted at Hemlock Creek sampling stations from July through December 1978. The yellowish-brown metallic precipitate was also present in McNabb Creek, and the water in McNabb and Hemlock Creeks had a brownish cast during the July 1981 sampling period. This brown coloration was probably due to suspended metallic precipitates.

Wilmouth and Kennedy (11) point out that although increasing pH can remove certain elements (aluminum, iron, and manganese) from solution, many flocs or precipitates that form, especially iron precipitates, are lightweight and tend to remain suspended rather than settle to the bottom. This mobilization appears to be a function of available alkalinity and flow characteristics. The water in Hemlock Creek also had a murky-white coloration during later samplings, particularly during August and December 1978. Because FHWA water-quality data showed relatively high aluminum concentrations at the mouth of Hemlock Creek, where confluent flow dynamics become altered, the whitish color may have been at least partly due to aluminum hydroxide suspension.

In December, manganese levels for McNabb Creek and reference sites showed little variation; however, concentrations in Hemlock Creek approached 0.45 mg/L, which was comparatively high. The aluminum concentration in McNabb Creek was 0.30 mg/L. It reached 1.90 mg/L at the upstream site on Hemlock and 0.65 mg/L at the downstream station during the month of December. Iron and copper concentrations were consistently low at all 13 stream stations. Elevated concentrations of zinc were found in affected streams, the highest value being 0.45 mg/L at the mouth of Hemlock Creek in December 1978.

Metal concentrations (as well as other water-quality parameters) measured by FHWA (12) at the headwaters of McNabb and Hemlock Creeks (above NaOH metering stations) appeared to be directly related to the amount of monthly rainfall. This relationship was most noticeable in December 1978 after a sharp increase in precipitation. Monthly precipitation increased from 7.3 cm in November to 15.7 cm in December 1978. An increase in acid-toxic metal contamination at the headwaters of McNabb and Hemlock Creeks in December was evident from water-quality data collected by FHWA. For example, from November to December 1978 at the headwater site on McNabb Creek, the aluminum concentration increased from 0.07 to 17.80 mg/L, manganese increased from 2.20 to 15.50 mg/L, and iron increased from 0.09 to 2.02 mg/L (12).

There appeared to be no correlation between fluctuations in water-quality parameters at the headwaters of McNabb and Hemlock Creeks and changes that occurred at the respective mouths of these two streams from May through December 1978 (12). Variability in metal concentrations, pH, and other water-quality parameters at the mouths of these two acid-mitigated streams was probably due to changes in stream discharge and the effectiveness of the NaOH treatment at any given time. FHWA water-quality data (12) showed the following metal concentrations at the headwaters and downstream sites of McNabb and Hemlock Creeks:

Site	Metal	Range (mg/L)
Headwaters	Aluminum	0.10-31.10
	Manganese	2.20-23.80
	Iron	0.01-9.90
Downstream	Aluminum	0.05-0.83
	Manganese	0.01-0.54
	Iron	0.01-0.90

Water-quality analyses during the mitigation period from May through December 1978 showed that NaOH stream neutralization measures improved water quality in downstream areas of McNabb and Hemlock Creeks by increasing the pH and precipitating potentially toxic metals. The effectiveness of NaOH additions varied somewhat for different months. This was probably due to fluctuations in stream flow and problems encountered with NaOH metering during the first few months of treatment. The physicochemical water quality of Hemlock Creek improved less than that of McNabb Creek and remained degraded in comparison with that of reference streams.

Postmitigation Period

A considerable change in the water quality of treated streams occurred after the termination of NaOH treatments in January 1979 and the completion of permanent soil blankets over exposed Anakeesta road-fill materials. The lack of buffering capacity in McNabb and Hemlock Creeks was reflected in the alkalinity values from January through March 1979, which were often measured as negative values (see Table 2). The pH fluctuated between 4.6 and 5.9 in McNabb and Hemlock Creeks during this period, and the values were usually from 1 to 2 pH units lower than at reference stations.

Because a decrease of 1 pH unit represents a tenfold increase in hydrogen ion concentration, these differences are substantial. Paired t-tests indicated that pH and total alkalinity values in McNabb and Hemlock Creeks were significantly lower ($p < 0.01$) than values obtained from reference streams. Values of pH at affected North River stream stations were consistently lower than those at upstream reference sites, but the pH was usually above 6.0. The pH of Laurel Branch was significantly lower ($p < 0.01$) than that of other reference streams that had similar pH and alkalinity levels.

Acidity, water hardness, and conductivity values were greater for streams receiving Anakeesta leachate than at upstream reference stations from January through March 1979 (Table 2). Although acidity values were greatest in McNabb and Hemlock Creeks during this period, the difference between affected and control streams varied for different sampling dates. Conductivity and water hardness were consistently high in leachate-receiving streams, and values obtained from McNabb and Hemlock Creeks were significantly greater ($p < 0.01$) than values obtained at reference stations.

Elevated concentrations of aluminum, manganese, and zinc occurred in the acid-receiving streams from March through June 1979 (Tables 2 and 3). Except for the February samples, levels of iron were usually low at all sampling stations. Differences in iron concentrations between reference and acid-affected stations varied for different sampling dates. No detectable levels of copper were measured from stream samples collected in April 1979. Concentrations of aluminum and manganese in McNabb and Hemlock Creeks ranged from 0.10 to 1.98 mg/L for aluminum and 0.09 to 0.54 mg/L for manganese during this period.

Poorer water quality in the mitigated streams revealed that acid-toxic metal leachates from pyritic Anakeesta road-fill materials continued to enter McNabb and Hemlock Creeks even after the soil blankets had been installed. Seasonal increases in rainfall during this period probably affected stream acid-metal leachate concentrations through the following mechanisms:

1. Increased flushing of pyritic oxidation products from the road embankments and sediment traps [during dry periods or periods of light rainfall, pyritic materials oxidize and hydrolyze to produce large quantities of acid and sulfate compounds that may be flushed off in a slug discharge during high-intensity storms (8)];
2. Increased dilution of the acid-toxic metal leachates due to increased stream discharge; and
3. Metallic precipitates that had settled on stream bottoms during NaOH treatments and were probably resuspended during scouring associated with high flow in these steeply sloped mountain streams.

Leaching of the pyritic Anakeesta material during this period could also have been affected by increasing pyritic oxidation rates associated with rising temperatures, high infiltration rates, and little vegetative covering (such as in winter and early spring) (8).

Additional time may be required for embankment stabilization and sealing processes (for example, established vegetative cover) to occur in mitigated Anakeesta road-fill areas of the Tellico-Robbinsville Highway. Further improvements in water quality can be anticipated after residual metal floc accumulations in the stream are flushed out.

Table 2. Water-quality parameters of North River drainages determined monthly from April 1978 through March 1979.

Item	McNabb Creek Premitigation (4/5/78)	McNabb Creek Mitigation (7/12/78)	McNabb Creek Postmitigation (1/3/79)	Hemlock Creek Premitigation (4/5/78)	Hemlock Creek Mitigation (7/12/78)	Hemlock Creek Postmitigation (1/3/79)
pH						
Mean	4.8	6.4	4.8	4.6	5.7	4.9
Range		6.2-7.2	4.6-5.1		5.5-6.2	4.7-5.0
Conductivity (μmhos/cm)						
Mean	60	88	66	58	91	61
Range		58-135	52-80		57-140	51-70
Acidity (mg/L as $CaCO_3$)						
Mean	19.8	8.1	13.0	22.8	10.2	12.0
Range		1.3-16.0	10.0-18.0		0.8-19.9	8.0-17.0
Alkalinity (mg/L as $CaCO_3$)						
Mean	2.0	7.3	-0.2	2.4	2.5	0
Range		4.0-11.4	-0.5-0.3		-0.1-4.6	-0.1-0
Hardness (mg/L as $CaCO_3$)						
Mean	26	20	24	24	19	25
Range		10-30	12-32		11-30	24-28
Selected metals (mg/L)						
Aluminum						
Mean		0.2[a]	1.4		1.1[a]	1.8
Range		0.2-0.3	0.9-1.7		0.3-1.9	1.7-2.0
Manganese						
Mean		0.2[a]	0.5		0.8[a]	0.3
Range		0.1-0.3	0.4-0.5		0.2-0.5	0.2-0.4
Iron						
Mean		0.1[a]	0.2		0.1[a]	0.2
Range		0-0.1	0-0.4		0.1-0.2	0.1-0.3

[a]Measured November-December 1978.

Table 3. Means and ranges of toxic metal concentration measured at 13 sampling stations in North River drainage from December 2, 1978, through June 28, 1979.

Stream	Sampling Station	Aluminum Mean	Aluminum Range	Manganese Mean	Manganese Range	Iron Mean	Iron Range	Zinc Mean	Zinc Range
		Metal Concentration (mg/L)							
Reference	1	0.06	ND-0.21	0.05	ND-0.25	0.05	ND-0.19	0.01	ND-0.07
	2	0.11	ND-0.31	0.04	ND-0.25	0.09	0.01-0.35	0.02	ND-0.10
	3	0.07	ND-0.25	0.06	ND-0.25	0.20	ND-1.40	0.02	ND-0.12
	4	0.11	ND-0.37	0.09	ND-0.40	0.07	ND-0.25	0.03	ND-0.12
	5	0.09	0.01-0.27	0.05	ND-0.25	0.11	0.03-0.40	0.02	ND-0.09
	6[a]	0.13	0.02-0.33	0.10	ND-0.44	0.13	0.03-0.34	0.04	ND-0.18
McNabb Creek	7	0.73	0.27-1.55	0.31	0.01-0.48	0.12	0.04-0.55	0.14	0.03-0.39
	8	0.80	0.17-1.67	0.35	0.06-0.54	0.08	0.01-0.40	0.09	ND-0.24
	9[b]	0.18	0.06-0.31	0.07	0.03-0.24	0.12	0.05-0.35	0.05	0.01-0.18
Hemlock Creek	10	0.56	0.10-1.35	0.25	0.09-0.44	0.14	0.02-0.60	0.16	0.02-0.48
	11	1.07	0.25-1.98	0.31	0.21-0.54	0.12	ND-0.33	0.17	0.03-0.32
	12[c]	0.27	0.05-0.70	0.11	0.04-0.24	0.11	0.05-0.21	0.08	ND-0.32
North River (recovery)	13	0.16	0.02-0.45	0.08	0.03-0.24	0.11	0.04-0.21	0.06	ND-0.22

[a]North River above McNabb confluence. [b]North River below McNabb confluence. [c]North River below Hemlock confluence.

FISH ASSESSMENT

Fish could not tolerate conditions in the streams that received Anakeesta drainages from the road-fill areas. Unpublished surveys by the U.S. Forest Service from June 6 through August 17, 1977, revealed that there were no fish in McNabb and Hemlock Creeks. North River fish populations were also depressed below the mouth of McNabb Creek in comparison with upstream sampling sites.

In later April 1978, before mitigation was initiated, a 4-day in-stream bioassay on rainbow trout was carried out in streams of North River drainage. At stations located at the mouths of McNabb and Hemlock Creeks, all test fish died after less than 24 hr of exposure. Although no rainbow trout died in the North River below McNabb Creek (station 9), 35 percent mortality was observed after 24-hr exposure at station 12 downstream of Hemlock Creek. Only 2 out of 80 rainbow trout died at reference stations during the test. Heavy rainfall (2.9 cm) that occurred during the 4-day bioassay may have flushed high levels of acid and toxic metal compounds into receiving streams. Acid drainage slugs caused by heavy or extended rainfall are a common occurrence in acid-mine drainages (8).

Although the acutely toxic conditions in McNabb and Hemlock Creeks were probably due to a combination of water-quality factors, low pH probably contributed to the death of fish during the in-stream bioassays. Specifically, the pH was 4.4 and 4.0 at the mouths of McNabb and Hemlock Creeks on the first day of the test (April 29, 1978). A pH of 3.7 was measured at the mouths of both streams by FHWA on May 3, 1978, the last day of the experiment (12). Most laboratory data show that a pH level below 5.0

is lethal to fish (13). An extensive survey of Pennsylvania streams polluted by acid-mine drainage showed that no fish were present in waters where the pH was below 4.5 (14). Although there are data that indicate that some fish can survive a pH as low as 4.0, the productivity of aquatic ecosystems is considerably reduced below a pH of 5.0 (13). For example, Menendez (15) reported that in laboratory tests sublethal pH levels (below 6.5) reduced egg hatchability and the growth of young brook trout.

Toxic metals evidently contributed to the lethal effects on rainbow trout in streams receiving Anakeesta drainage. As discussed earlier in the water-quality analysis, elevated concentrations of aluminum, manganese, and zinc (in comparison with control streams) were found in McNabb and Hemlock Creeks during the study period. Many fish examined during the quarterly in-stream bioassays showed obvious signs of gill hyperplasia (a swollen, congested condition). Toxic metal poisoning at acute levels has been shown to cause this symptom (16-19).

Aluminum (17,20,21) and zinc (16,18,19) have been found to be lethal to fish at rather low concentrations, particularly in poorly buffered soft waters. Freeman and Everhart (17) suggest that the safe concentration of either dissolved or suspended aluminum for rainbow trout is well below 0.5 mg/L. Chapman (16) has listed the results of toxicity tests in which lethal zinc concentrations for rainbow trout ranged from 0.24 mg/L (at a pH of 7.2) to 0.85 mg/L (at a pH of 7.1). McKee and Wolf (22) suggest that 1 mg/L of ionic manganese has no deleterious effects on fish. However, the toxicity of manganese (as well as other metals) varies for different species of fish. Aluminum and manganese concentrations measured by FHWA in McNabb and Hemlock Creeks in August 1977 (before mitigation began) greatly exceeded levels reported to be toxic to fish (Table 1).

The toxicity of aqueous metals to fish is modified by many water-quality factors, including water hardness, dissolved oxygen, temperature, pH, and the presence of other metals (16). Although metals are generally more toxic to fish in soft water (which is characteristic of streams in the study area), the toxic nature of metals will vary greatly under different water-quality conditions, particularly chelating organic substances.

Mitigation Period

Mitigated streams showed a general improvement in physicochemical water quality during the period when NaOH neutralization measures were used (Table 2). The positive trends were supported by results of in-stream bioassays done during August and December 1978. Rainbow trout mortalities ranged from 0 to 45 percent after 96 hr of exposure at mitigated sites in August 1978, whereas before mitigation there had been a 100 percent mortality rate within 24 hr. Losses occurred at all stations during the August test, which suggests that the trout had been under stress before testing. Stress due to handling and temperature was apparent while the fish were being transported to study sites during the hot summer conditions. Insufficient acclimation to stream waters may also have contributed to fish mortality in August. Because high mortality (85 percent) was observed at station 6 (a reference station), it is unreasonable to assume that the 45 percent fish mortality in Hemlock Creek was due solely to lethal water-quality conditions.

Only one rainbow trout died at station 7 in Hemlock Creek during the December 1978 bioassay, and no fish died in the other acid-receiving streams during that month's tests. The 89 percent loss observed after 96 hr at station 5 in the North River (a reference station) could only be explained by poor positioning of the test chambers within the stream because no fish mortalities were observed at the other reference sites.

Fish population samples collected in August and December 1978 substantiated these results, revealing a subtle migration of rainbow trout and creek chubs back into the lower reaches of McNabb and Hemlock Creeks. Schools of small fish (possibly creek chubs) were also seen near the mouths of these mitigated streams during invertebrate sampling in August, September, and November 1978. Good populations of rainbow trout were found in reference streams during the quantitative fish collections. Blacknose dace, creek chub, and northern hog sucker were also taken from reference sites on Laurel Branch. Brook trout was the only additional species found in each of the Sugar Cove samples in August and December 1978. Although the number of fish collected in McNabb and Hemlock Creeks was low compared with reference streams, these results indicated that fish were moving back into mitigated drainages.

Because of excessively high pH levels in the headwaters of McNabb and Hemlock Creeks (below NaOH treatment stations), biological accommodations seen at downstream stations during this period were not expected in upstream areas of these NaOH-mitigated streams. Laboratory data have revealed that a pH range of 9 to 10 was harmful to some species of fish and a pH greater than 10 was lethal to all other test species (13). Witschi and Ziebell (23) also reported that a pH of 9.5 to 10.0 was acutely lethal to rainbow trout that had been acclimated to a pH of 7.2. Thus, it is reasonable to assume that fish could not tolerate the high pH conditions in the upper reaches of McNabb and Hemlock Creeks during the NaOH additions.

Postmitigation Period

After the completion of more permanent surface sealing of road embankments and the subsequent termination of NaOH treatments in January 1979, the physicochemical water quality of mitigated streams degraded in comparison with that of reference streams. In-stream bioassays were done in March and June 1979 to evaluate the initial effectiveness of permanent mitigation measures. In these 96-hr tests, acutely lethal conditions (100 percent fish mortalities) were observed at downstream sites on McNabb and Hemlock Creeks. Only a few rainbow trout died at reference and North River stations downstream of the mitigated streams in both the March and June 1979 studies. During these test periods, no fish were collected by electrofishing on McNabb and Hemlock Creeks. Quantitative fish samples collected from reference streams in March and June 1979 were comparable to those collected in earlier sampling efforts.

The pH ranged from 4.6 to 5.6 at McNabb and Hemlock Creek sampling stations from January through June 1979. Concentrations of manganese and aluminum approached 0.6 and 2.0 mg/L, respectively, in these streams. These studies reveal that toxic materials were still entering streams 6 months after completion of the highway embankment soil blankets. Rainbow trout and other native species of fish could not survive mitigated stream conditions where there was a toxic combination of substances. As suggested earlier in the discussion of water quality, an improvement in stream water quality may be expected over time once embankment stabilization occurs in the mitigated road-fill areas of the Tellico-Robbinsville Highway.

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Highway Impacts on Wetlands: Assessment, Mitigation, and Enhancement Measures

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The conservation of wetland acreage in the United States, wherever and whenever practicable, is a national policy objective. This had led to an increased awareness of the need for making wise land use decisions, especially when modification of the natural environment is anticipated. Federal agencies are required to avoid construction in wetlands whenever there is a practicable alternative. However, often there is no practicable alternative. It is important, therefore, to understand the functions, values, and ecological interrelationships of wetland systems so that an appropriate mitigation plan can be developed. General wetland types and their basic functions and values are identified, and highway construction impacts, impact assessment, and mitigation and enhancement procedures are discussed. Special emphasis is given to the reconstruction of wetlands affected by highway construction.

Executive Order 11990, Protection of Wetlands, sets forth a national policy that requires avoiding to the extent possible the long- and short-term adverse impacts associated with the destruction or modification of wetlands. Over the past decade there has developed an increasing awareness of the need for making wise land use decisions to reduce or eliminate adverse modification of the natural environment, including wetlands. Estimates indicate that nearly half of the 120 million acres of wetlands inventoried in the 1950s has already been lost (1). This loss has come largely from the alteration and destruction of wetlands through artificial draining, dredging, and filling. Although there has been a decrease in the percentage of remaining wetlands being lost annually, the subject remains one of concern.

Federal agencies are required to avoid construction in wetlands whenever there is a practicable alternative. This policy applies to any project located in or having an effect on wetlands. FHWA is committed to this policy during the planning, construction, and operation of highway facilities and projects.

DEFINITION OF WETLANDS

An awareness of local wetland statutes and ordinances and their corresponding definitions is extremely important in the environmental impact analysis of proposed highway projects. There is no single, indisputable definition of wetlands because of a high degree of diversity characterized by the continual gradation between dry and wet environments and because reasons and needs for defining wetlands vary.

The definition most commonly accepted by the U.S. Department of Transportation is that of the U.S. Army Corps of Engineers. The Corps of Engineers defines wetlands as areas inundated or saturated by surface water or groundwater at a frequency and duration sufficient to support--and that under normal circumstances do support--a prevalence of vegetation typically adapted for life in saturated soil conditions (33 CFR § 323.2c). Consequently, many types of land can be considered. Under the Corps of Engineers definition, wetlands generally include areas such as swamps, marshes, and bogs.

WETLAND TYPES

A swamp is a type of wetland that is often waterlogged in winter and early spring but may be quite dry in the summer. Swamps are characterized by a predominance of woody plants. Swamp vegetation includes willow, oak, maple, gum, alder, and cypress. Swamps usually develop in wet upland depressions, at the edges of lakes and ponds, and along the borders or floodplains of streams and rivers (2).

Marshes can be either saltwater or freshwater. Salt marshes stretch in an almost continuous chain of undulating grasses along the Atlantic Coast and the Gulf of Mexico and account for less than 10 percent of total U.S. wetlands (2). Salt marshes also occur sporadically along the West Coast. Salt marshes are inundated daily by tides, and vegetation consists of salt tolerant plants such as cord grass and marsh hay.

Freshwater marshes account for more than 90 percent of total U.S. wetlands (2). Freshwater marshes may occur inland or adjacent to the coast in low-lying depressions and are most often covered with shallow water. Marshes may be fed by groundwater, surface springs, streams, rainwater, runoff from the surrounding terrain, or all of these. Marsh vegetation is usually characterized by soft-stemmed plants. Vegetation consists of grasses, sedges, waterlilies, reeds, and arrowheads.

The bog is a freshwater wetland most common in the northern and north-central states. Bogs often form in glaciated depressions in forested regions. A bog has very restricted drainage and therefore has almost no inflow or outflow. For this reason, dead organic matter accumulates as peat in layers that are often 40 ft or more in depth (2). Vegetation is characterized by acid-tolerant plants and includes cranberries, blueberries, sedges, and insectivorous plants.

The important point to remember about wetlands is that the dominant factor is saturation with water, which determines the nature of soil development and the types of plant communities that live in the soil or on its surface. Thus, soil types and species of vegetation are the most important physical indicators of wetlands (1).

VALUE OF WETLANDS

Wetland systems serve many functions and provide many benefits. Wetlands provide the vegetative material that is the base for many aquatic and terrestrial food chains. Moreover, vegetative production in wetland systems can be considerable because these aquatic environments act as nutrient traps. Aquatic vegetation can assimilate these nutrients and produce tremendous quantities of plant material. The rates of gross primary productivity in certain types of wetlands are among the highest recorded for any natural systems. Consequently, the potential for supporting large plant and animal populations of diverse species is also high.

Wetlands also provide a vital breeding, feeding, and nursery habitat for many species of waterfowl, fur-bearing mammals, and fishes. The dependence of such species on wetlands at some time in their life cycle is of great economic importance. Many wetlands such as marshes and swamps often act as highly effective flood and erosion buffers. The expansives of