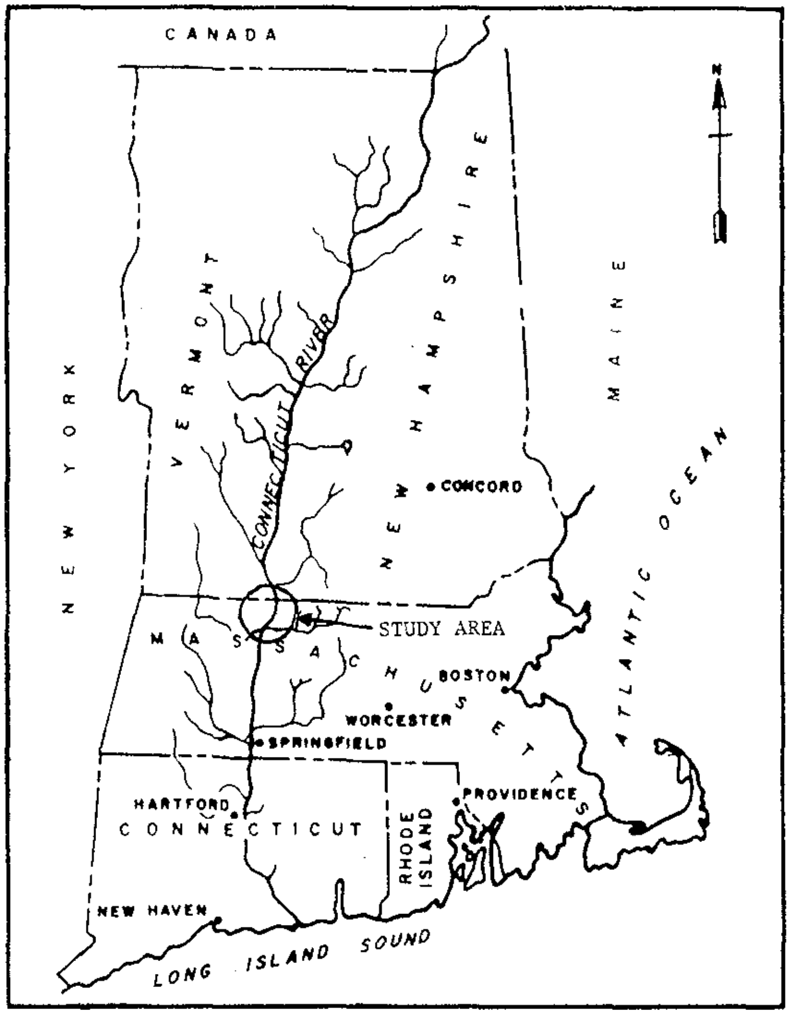
General Investigation Study
Connecticut River Streambank Erosion

Connecticut River

Turners Falls Dam to State Line, MA.



January 1991

US Army Corps
of Engineers
New England Division

GENERAL INVESTIGATION STUDY
CONNECTICUT RIVER STREAMBANK EROSION

CONNECTICUT RIVER
TURNERS FALLS DAM TO STATE LINE, MA.

U.S. Army Corps of Engineers
New England Division
424 Trapelo Road
Waltham, Massachusetts

JANUARY 1991

Executive Summary

A congressionally authorized resolution, adopted August 3, 1989, approved a reconnaissance level study to investigate streambank erosion along the Connecticut River from Turners Falls north to the Massachusetts state line. This report is the result of that resolution and study.

This study is limited in scope and does not address all issues normally discussed in a Corps of Engineers Reconnaisance Report. The rationale behind the limit in scope is an effort to eliminate duplication of work. Northeast Utilities, a public utility company, is producing a "Masterplan Study" which concerns this same reach of the Connecticut River. This Masterplan Study is addressing all the issues which would normally be covered in a Corps of Engineers Reconnaissance Study. Because Northeast Utilities is being required to produce this report by the Federal Energy Regulatory Commission (FERC) in order to complete the licensing procedure for its Northfield Mountain Pumped Storage Project, which affects this reach of the river, the Corps has elected to scale back the scope of work of our Reconnaissance Study.This reduction was coordinated with public, private and congressional interests.

The primary objective of this Reconnaissance Study was to identify erosion areas in the reach from Turners Falls Dam north to the Massachusetts state line, and compare this data to similar data collected for a 1979 Corps of Engineers report. The 1979 report addressed a much larger reach of the river, but did include the section from Turners Falls Dam to the state line. In addition, this study updates hydrologic information related to this reach to reflect events from the past 12 years.

The results of this study show that riverbank erosion has increased dramatically since 1979, almost a three-fold increase. Approximately one-third of the 148,000 linear feet of shoreline in this reach is undergoing some form of active erosion. In addition, the Turners Falls pool has remained the most dynamic pool on the Connecticut River, with daily fluctuations in water level averaging 3.5 feet. Hydrologically, the last 20 years has seen higher than normal day-to-day river flow at the Turners Falls gage as well as two major floods. Recreational boating activity has also increased dramatically with the construction of public access points on the river. These factors, coupled with the natural environment, have significantly increased erosion in the reach over the past 12 years.

GI Reconnaissance Report
Connecticut River Streambank Erosion
Turners Falls Dam to State Line, Massachusetts

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INTRODUCTION

Study Authority

A congressionally authorized resolution, adopted August 3, 1989, approved a reconnaissance level study to investigate streambank erosion along the Connecticut River from Turners Falls north to the Massachusetts State Line, and to review previous reports pertaining to this reach of the river. The resolution reads as follows;

> *Resolved by the Committee on Public Works and Transportation of the United States House of Representatives, that the Board of Engineers for Rivers and Harbors is requested to review previous reports on streambank erosion along the Connecticut River from Turners Falls to Massachusetts, with a view to determining whether any improvements are advisable along the Connecticut River, Massachusetts-New Hampshire state line in the interest of streambank protection.*

Scope of Study

Northeast Utilities, a public utility company which operates a pumped storage hydroelectric project affecting this reach of the Connecticut River, has been required to undertake a study to examine the erosion conditions in this reach by the Federal Energy Regulatory Commission (FERC). The Northeast Utilities study was required in order to meet operating license requirements established by FERC. Coincidentally, the timetable for the Northeast Utilities Study was similar to the timetable for the Corps study, and many of the work items in the respective scopes of work were identical. In an effort to eliminate the duplication, and given that Northeast Utilities was being required by FERC to accomplish the study, the Corps elected to limit the scope of work of the Reconnaissance Study.

The primary objective of this Reconnaissance Study was to identify erosion areas in the reach of the Connecticut River from the Turners Falls Dam north to the Massachusetts State Line. This data about current erosion sites can then be compared to erosion sites identified in a 1979 Corps of Engineersreport which also looked at this reach of the river. This will show how erosion conditions have changed in the 12 years between studies. In addition, the report will update the hydrologic information concerning this reach to reflect events from the past 12 years. Some new hydrologic data is developed, however, the 1979 Corps of Engineers report is used to obtain as much hydrologic information as possible. In the 1979 study, causes of streambank erosion, including natural hydrologic conditions, powerplant operation, and boat waves, etc., are discussed for the 141 mile stretch of the Connecticut River from Turners Falls Dam (River Mile 122) to the headwaters of Wilder Reservoir in Haverhill, New Hampshire and Wells River, Vermont (River Mile 263). Additional storm event data after 1979 is included in this report, since not only is it readily available but the events provide some of the most severe erosional characteristics in the reservoir.

Prior Studies

In the past, the Corps of Engineers has completed studies and reports which addressed the reach of the Connecticut River from Turners Falls north to the Massachusetts State Line, but none have been specifically concerned with just this reach. There are, however, two prior reports which have special significance in relation to this Reconnaissance Report.

One of these reports, published in 1980, concerned the design and construction of the Corps of Engineers Streambank Demonstration Project at Northfield, Massachusetts. This project was authorized by the authority of the Streambank Erosion Control Evaluation and Demonstration Act of 1974, Section 32, Public Law 93-251. The purpose of the project was to showcase innovative methods of streambank protection, and to gain experience with these methods. The site chosen was on the east bank of the Connecticut River, immediately downstream of the Route 10 bridge, and was about 2000 feet in length. The area was eroding at a rate, estimated in 1980, of about 1 to 3 feet per year. The site was divided into three approximately equal lengths, each showcasing a different stabilization method. The three methods chosen were a precast cellular concrete block mattress, a used auto tire wall, and a used auto tire mattress. All three reaches utilized vegetative protection on the upper bank, with the structural measures applied only on the lower bank. While no detailed monitoring plan has been established during the 10 years that the project has been in existence, occasional visits to the site have indicated that each of the measures used has functioned well, and no rehabilitation work has been required to date. This demonstration project has shown that non-traditional structural bank stabilization measures, using readily available materials and relatively simple construction techniques that local government agencies and private land owners can employ, can be effective and long-lasting in this reach of the Connecticut River.

The other report which has importance relative to this Reconnaissance effort is the 1979 Corps of Engineers Report on Connecticut River Streambank Erosion in Massachusetts, New Hampshire, and Vermont. This study, conducted in accordance with a contract between the Army Corps of Engineers and Colorado State University Research Institute, examined a reach of the Connecticut River from Turners Falls Dam, MA, north to the headwaters of the Wilder Hydro Pool in Haverhill, NH, a distance of about 141 river miles. (The current Reconnaissance Study was confined to the lower 15 miles of that reach.) The 1979 study identified areas of erosion in the reach, analyzed the causes of bank erosion, and developed solution alternatives. The site identification material contained in the report serves as a comparative baseline for the data collected in this report so that changes in erosion sites during the past 12 years can be identified.

Study Participants and Coordination

Throughout the study process, contact has been maintained with officials of various public and private agencies concerned about the erosion conditions in this reach of the Connecticut River. By attending public meetings and workshop meetings sponsored by Northeast Utilities as part of their Masterplan study process, the Corps has been provided with a flow of information from local residents and from other involved agencies, including local, state, and Federal. Personnel from Northeast Utilities and their Masterplan consultant were particularly helpful.

The principal points of contact for this study were:

Charles E. Momnie	Northeast Utilities
John Devine	Northrup, Devine and Tarbell
Robert J. Mitchell	Northrup, Devine and Tarbell
Tony Matthews	Chairman-Combined Conservation Commissions of Gill, Erving Northfield, Montague
James Ogsbury	Assistant to U.S. Representative Silvio Conte, First U.S. Congressional District, MA

The Report Methodology

The main objective of this report was to identify areas of erosion on the reach of the Connecticut River from Turners Falls Dam north to the Massachusetts state line. This data was then compared with similar data collected for a 1979 Corps of Engineers report. In order to make this comparison of old and new data valid, the level of details and manner of data collection for the current work needed to be performed similarly to 1979 methods. To this end, erosion sites were identified visually both from the land and the river. Pertinent facts for each site were estimated and recorded at the same time, based again on a visual inspection. This methodology is consistent with that used in 1979. While more accurate site identification is possible through actual measurements and closer inspection of each site, this would not have been consistent with 1979 methods, and was considered unnecessary. In addition, a reconnaissance level effort would not normally involve detailed site identification and analyses.

References

a. Report on: Connecticut River Streambank Erosion Study, Massachusetts, New Hampshire and Vermont, Corps of Engineers, New England Division, November 1979.

b. Water Resources Investigation, Connecticut River Streambank Erosion Study, Preliminary Report, Corps of Engineers, New England Division, December 1976.

c. Flood Insurance Study, Town of Gill, Massachusetts, Federal Emergency Management Agency, December 1979.

d. Flood Insurance Study, Town of Northfield, Massachusetts, Federal Emergency Management Agency, March 1980.

e. Final Report to Congress, The Streambank Erosion Control Evaluation and Demonstration Act of 1974, Section 32, Public Law 93-251, December 1981.

f. Report on Connecticut River Basin Bank Erosion Study, Reconnaissance Report, New England River Basins Commission, Technical Committee on Bank Erosion, June 1974.

g. River Bank Erosion on the Connecticut River at Gill, Massachusetts:its Causes and its Timing; John B. Reid, Jr., Professor of Geology, Hampshire College, May 24, 1990.

BASIN DESCRIPTION

Connecticut River Basin

This basin is comprised of 11,265 square miles of drainage area in Vermont, New Hampshire, Massachusetts, and Connecticut, including 114 square miles in Quebec. Long and narrow in shape, it has a maximum length of about 280 miles and a maximum width of approximately 60 miles. A basin map is shown on Plate 1.

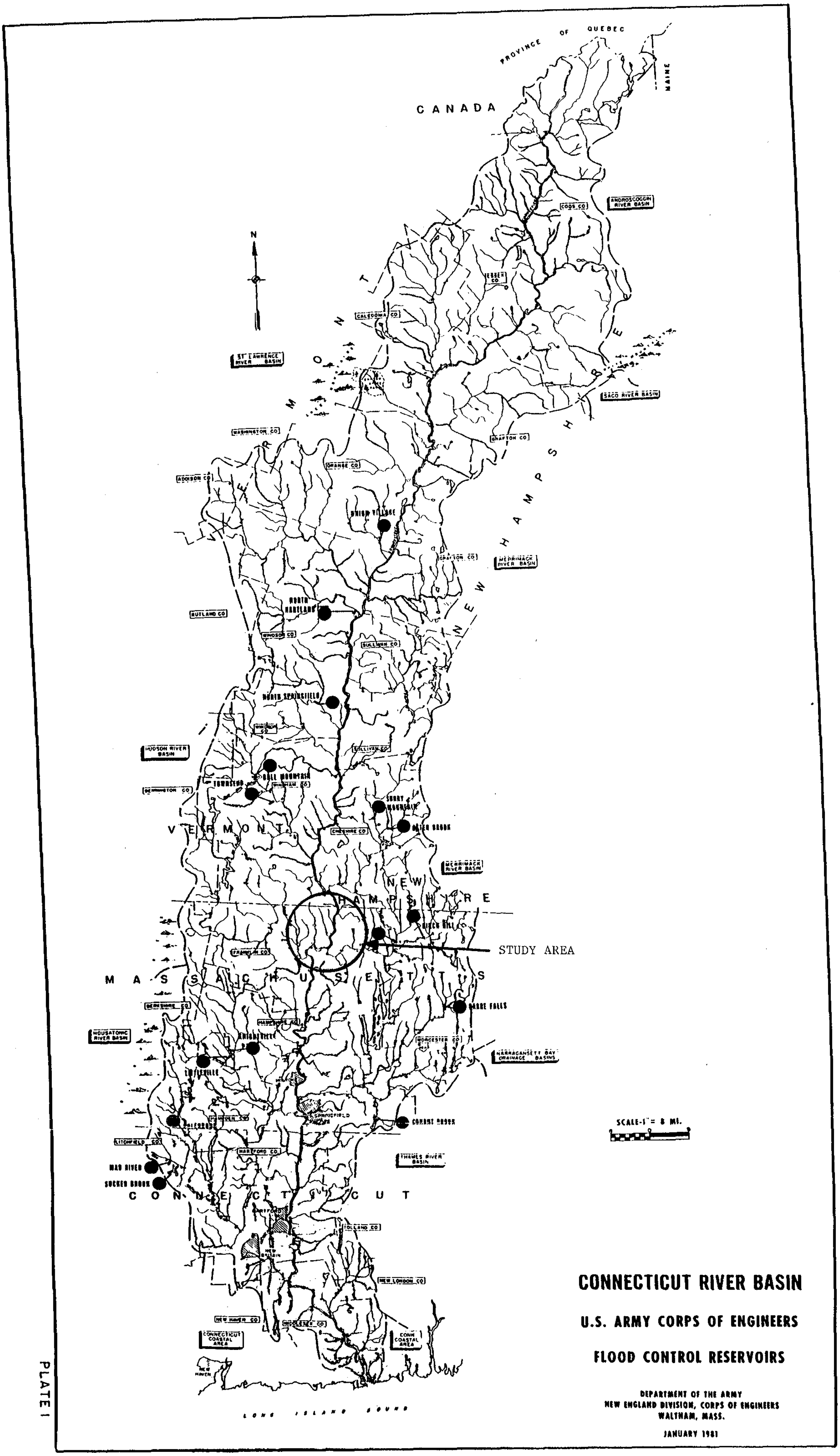
The main stem Connecticut River rises in the Connecticut Lakes of northern New Hampshire adjacent to the Canadian border. The river follows a general southerly course along the approximate centerline of its watershed for approximately 404 miles to its mouth on Long Island Sound at Saybrook, Connecticut. In the first 29 miles below its source, the river flows entirely within the State of New Hampshire, then for a distance of about 238 miles, between New Hampshire and Vermont, the western edge of the river forming the boundary; and, finally, 67 miles across Massachusetts and 70 miles in Connecticut, emptying into Long Island Sound.

The lower 60-mile reach of the river to approximately 8 miles above Hartford is tidal. The fall in the remainder of the river is about 2,200 feet with the steepest portion averaging 30 feet per mile, occurring in the first 30 miles below the Third Connecticut Lake outlet. The fall averages about 2 feet per mile from Wilder Dam, Vermont to the head of tidewater.

The principal tributaries are the Passumpsic and Ammonoosuc Rivers in the northern headwaters; the White and Ashuelot Rivers in the central basin; and the Deerfield, Chicopee, Westfield, Millers, and Farmington Rivers in the southern part of the basin.

The watershed includes three general types of terrain: the heavily forested northern mountains, the wooded central plateau, and the low and rolling southern regions. About 70 percent of the basin is covered by woodland or forests. Agriculture, the second largest land use, includes dairying, poultry raising, and small-scale general farming. Industry is generally located in the lower part of the basin. The greatest concentration of population is located along the lower Connecticut River in Massachusetts and Connecticut.

There has been considerable development within the basin for flood control, navigation, hydroelectric power, recreation, fish and wildlife, and municipal and industrial water supply. Sixteen reservoirs constructed by the Corps of Engineers provide a usable storage capacity of 526,630 acre- feet for flood control and 40,100 acre-feet for municipal water supply. A list of projects is provided in Table 1. The first eight flood control watersheds are upstream from Turners Falls Dam. There are also 23 existing non-Federal reservoirs or lake systems with greater than 7,000 acre-feet of usable storage. Pertinent data are shown in Table 2. The first eight main stem reservoirs are upstream from Turners Falls Dam as well as two tributary water bodies on the Mascoma and Sugar Rivers. These non-Federal reservoirs, which have enough storage to significantly affect streamflow, are operated for power, water supply or recreation purposes with no storage allocated for flood control. Power dams are generally operated for peaking purposes, although during springtime or when riverflows are high, many dams generate power continuously. There are



CONNECTICUT RIVER BASIN

U.S. ARMY CORPS OF ENGINEERS

FLOOD CONTROL RESERVOIRS

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION, CORPS OF ENGINEERS
WALTHAM, MASS.

JANUARY 1981

PLATE I

TABLE 1

CONNECTICUT RIVER BASIN
CORPS OF ENGINEERS FLOOD CONTROL RESERVOIRS

Reservoir (Date Completed)	Location	Drainage Area (sq.mi.)	Storage Total (acre-feet)	Storage Flood Control (acre-feet)	Present Uses*
Union Village, VT (1950)	Ompompanoosuc River	126	38,000	38,000	FC
North Hartland, VT (1961)	Ottauquechee River	220	71,800	71,100	FC,R
North Springfield, VT (1960)	Black River	158	50,500	50,000	FC,R
Ball Mountain, VT (1961)	West River	172	54,600	52,600	FC,R
Townshend, VT (1961)	West River	106 (net) 278 (gross)	33,600	32,800	FC,R
Surry Mountain, NH (1941)	Ashuelot River	100	33,000	31,700	FC,R
Otter Brook, NH (1958)	Otter Brook	47	18,300	17,600	FC,R
Birch Hill, MA (1941)	Millers River	175	49,900	49,900	FC
Tully, MA (1949)	East Branch Tully River	50	22,000	20,600	FC,R
Barre Falls, MA (1958)	Ware River	55	24,000	24,000	FC
Conant Brook, MA (1966)	Conant Brook (Chicopee River)	7.8	3,740	3,740	FC
Knightville, MA (1941)	Westfield River	162	49,000	49,000	FC
Littleville, MA (1965)	Middle Branch Westfield River	52	32,400	23,000	FC,WS
Colebrook River, CT (1969)	West Branch Farmington River	118	97,700	50,200	FC,WS,C
Mad River, CT (1963)	Mad River (Farmington River)	18	9,700	9,510	FC,R
Sucker Brook, CT (1969)	Sucker Brook (Farmington River)	3.4	1,480	1,480	FC
	TOTALS - 16 SITES	**1,570.2**	**589,720**	**526,630**	

* **FC** - Flood Control, **R** - Recreation, **WS** - Water Supply, **C** - Conservation

TABLE 2

CONNECTICUT RIVER BASIN
PERTINENT DATA - NON-FEDERAL RESERVOIRS
(With Usable Storage Capacities in Excess of 7,000 Acre-Feet)

Reservoir	River	Drainage Area (sq.mi.)	Owner	Usable Storage (ac/ft)	Purposes*
Second Connecticut Lake	Connecticut	45	New England Electric System	11,600	CSP,R
First Connecticut Lake	Connecticut	82	New England Electric System	76,400	CSP,R
Lake Francis	Connecticut	170	New Hampshire (State)	99,300	CSP,R
Moore	Connecticut	1,600	New England Electric System	114,000	P,R
Comerford	Connecticut	1,635	New England Electric System	29,400	P,R
Wilder	Connecticut	3,375	New England Power Company	13,400	P,R
Bellows Falls	Connecticut	5,414	New England Power Company	9,600	P,R
Vernon	Connecticut	6,266	New England Power Compnay	12,000	P,R
Turners Falls/Northfield Mtn	Connecticut	7,138	Western Mass. Electric Company	25,500	P,R
Holyoke	Connecticut	8,309	Holyoke Water Power Company	7,000	P,R
Mascoma Lakes	Mascoma	182	New England Electric System	24,400	P,R
Sunapee Lake	Sugar	46	New Hampshire (State)	19,800	R,WS,P
Somerset	Deerfield	30	New England Electric System	57,400	CSP,R
Harriman	Deerfield	184	New England Electric System	116,000	P,R
Bear Swamp/Fife Brook	Deeffield	250	New England Electric System	9,200	P,R
Quabbin	Swift	186	MDC (Boston)	1,235,000	WS
Borden Brook, Cobble Mtn	Westfield	8 + 46	Springfield, MA (City)	77,900	WS
Otis	Farmington	17	Mass. Dept. of Natural Resources	17,900	R
West Branch (Hogback)	Farmington (West Branch)	122	MDC (Hartford)	20,100	WS
Barkhamsted	Farmington (East Branch)	54	MDC (Hartford)	93,000	WS
East Branch	Farmington (East Branch)	61	MDC (Hartford)	9,000	WS
Nepaug	Nepaug	32	MDC (Hartford)	28,500	WS
Shenipsit	Hockanum	17	Rockville Water & Aqueduct Co.	11,100	WS
TOTAL				2,117,500	

* P - Power, R - Recreation, WS - Water Supply, CSP - Conservation Storage for Power

important hydropower dams on the main stem Connecticut River throughout its length. The Moore, Comerford, and Wilder power projects are in northern areas upstream of White River Junction. Bellows Falls, Vernon and Turners Falls dams are located along the central reaches, and Holyoke dam is in the southern portion of the basin.

Study Reach

The riverine reach investigated for this erosion study of Turners Falls Reservoir is approximately 14 miles long, extending from Turners Falls Dam in Massachusetts northward along the Connecticut River to the Massachusetts State line. Although not in the study reach, there is a hydrologically similar portion of the river located as far as 6 miles upstream from the Massachusetts State line extending to the Vernon Dam in Vermont and New Hampshire. Included in this overall reach are the towns of Montague, Northfield, Erving, and Gill, Massachusetts, and Vernon, Vermont and Hinsdale, New Hampshire. A map of the study area is shown in Plate 2.

The main tributaries in this reach of the river are the Millers (D.A. = 375 sq. mi.) and Ashuelot (D.A. = 420 sq. mi.) Rivers located approximately 4 and 18 miles above Turners Falls Dam, respectively. The Ashuelot River, which begins in Washington, New Hampshire, drops 1,235 feet in its first 58 miles and another 240 feet in the lower 6 miles. The Millers River rises in Ashburnham, Massachusetts, flowing in a general westerly direction about 45 miles to its confluence with the Connecticut River at Erving, Massachusetts. The total fall is estimated at 900 feet. The main stem Connecticut River has drainage areas of 7,138 and 6,266 square miles at Turners Falls and Vernon Dams, respectively.

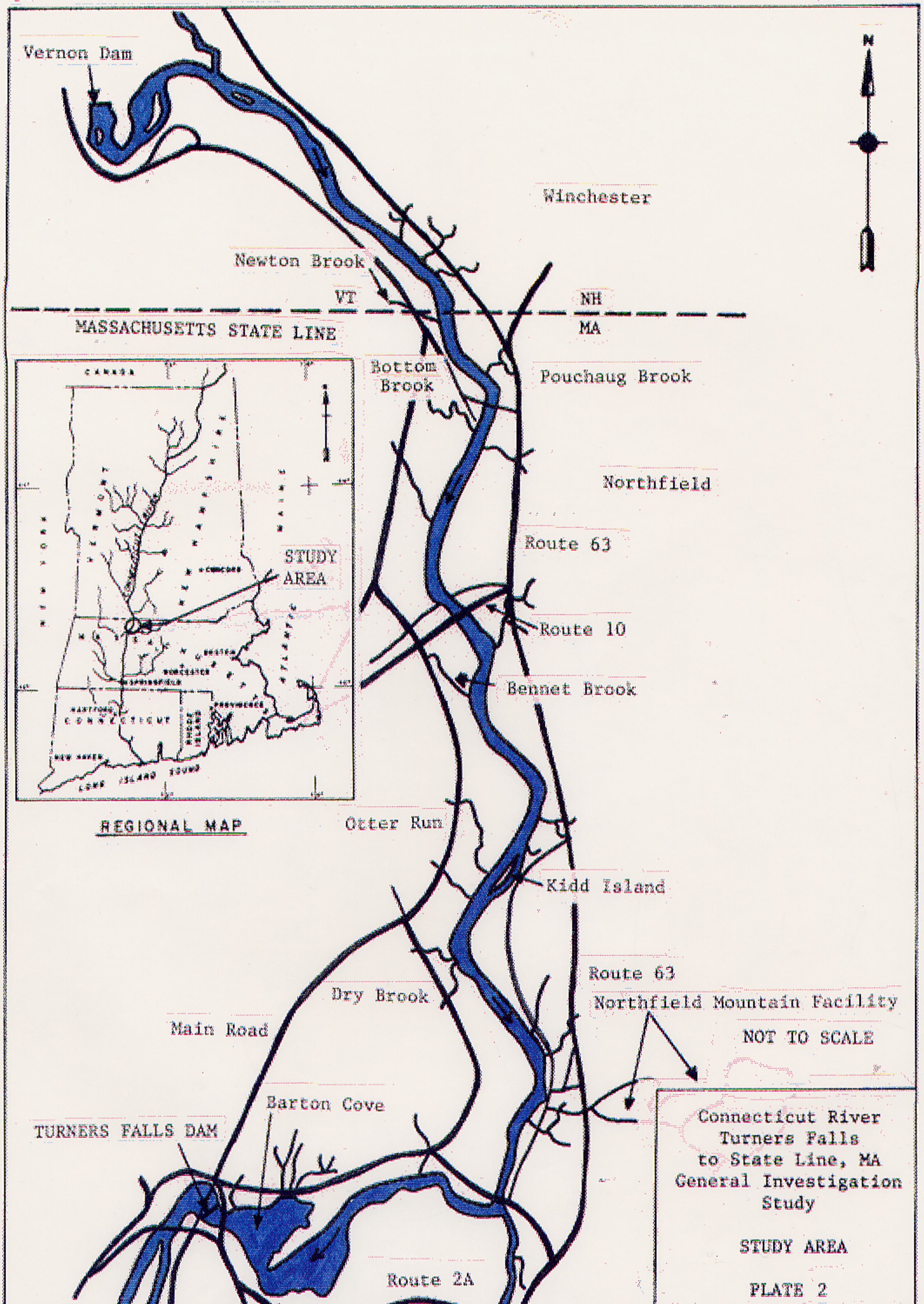
HYDROELECTRIC GENERATING FACILITIES

General

Three hydroelectric generating facilities directly impact the day-to-day hydrodynamics of the study reach - Vernon, Turners Falls, and Northfield Mountain. The two run-of-the-river projects, Turners Falls and Vernon (constructed in 1904 and 1910, respectively), were the primary generating stations exerting influence for many years. In 1971, the Northfield Mountain Pumped Storage Project, located about 5 miles upstream from Turners Falls Dam, was completed, and the height of Turners Falls Dam was increased, significantly altering the hydrodynamics of the reach. The joint operation of the Turners and Northfield projects has significantly changed the daily regime of the river in the study area, resulting in larger and quicker pool fluctuations.

Generally, Connecticut River flow at Vernon is controlled by the power station operation at the dam. Only during floods is excess water passed over an uncontrolled spillway on its way toward Turners Falls. Inflows into the Turners Falls pool, as a result of discharges from Vernon Dam, normally vary between 1,000 and 10,400 cfs. When flows are in this range, all water passes through the Vernon turbines , generating power. Flow releases beyond 12,000 cfs are controlled by the maximum pool level approved in the Federal Energy Regulatory Commission's (FERC) operating procedures of Vernon Dam's license. A list of maximum pool levels and operational procedures

CORPS OF ENGINEERS U.S. ARMY



for Vernon Dam taken from New England Power Company's operation manual, dated September 1987, is presented in Table 3.

The 20-mile reach downstream from Vernon Dam and upstream from Turners Falls Dam serves as a power pool for the Turners Falls facilities and also as the lower reservoir for the Northfield Mountain Pumped Storage Project. Hydropower releases from this power pool are made through turbines at the dam and turbines at the end of a power tunnel at Cabot hydroelectric station located about 2.5 miles downstream from the dam. Control of releases at Turner Falls rests with operation of the Northfield Mountain Pumped Storage Project. During most of the year, rates of water discharged into and pumped out of the lower reservoir from operation of the pumped storage plant will be the same magnitude as natural flow in the river. Additional inflows from the intervening tributaries, Millers and Ashuelot Rivers, vary depending on the season and type of hydrologic year. These variations in flow add to the dynamic situation that exists in Turners Falls pool and are a significant factor when studying bank erosion.

Northfield Mountain Pumped Storage Project Operation

Normally, the Northfield plant, with tailrace located approximately 5 miles upstream from Turners Falls Dam, operates on a weekly cycle. Water from the upper reservoir is discharged through the turbines into the lower reservoir (the river) to provide power during daytime peak-demand hours during five weekdays. Some water is pumped from the lower to the upper reservoir during off-peak hours at night. The remainder necessary to fill the upper reservoir is pumped on the weekend. Therefore, on a weekly cycle the upper reservoir is generally full only on Monday morning.

The maximum combined rate of water release from the upper to lower reservoir through the four pump turbines during the Northfield generation cycle is approximately 20,000 cfs. The maximum pumping rate of water from the lower to upper reservoir is about 12,000 cfs. Generation can only take place at Northfield Mountain if releases from Northfield can be stored in the lower reservoir without increasing the Turners Falls water surface elevation above allowable levels shown in Table 4. This was taken from operating procedures described in Northeast Utilities Service Company's Reservoir Flow Management Procedures, dated March 1972. There are no set regulations regarding the maximum amount of pool fluctuation during the day; however, pool levels must not fall below 176.0 feet NGVD at any time nor pool levels rise above the previously described stages. Typically, pool fluctuations may average as much as 3.5 feet/day over the course of a weekly cycle, although significantly higher fluctuations may occur in shorter time periods.

TABLE 3

VERNON DAM OPERATING SUMMARY

Flow Rate (cfs)	Operational Procedure	Maximum Pool Level (ft, NVGD)
12,000 and less	Use plant capacity up to 12,000 cfs	220.1
12,000 - 45,000	Use plant capacity plus operate selected spillway gates	219.6
Flows over 45,000	Use plant capacity plus operate additional selected spillway gates	218.6
Flows over 85,000	Uncontrolled flow	

Notes: 1. Top of flashboards at elevation 220.13 feet, NGVD.
2. All flashboard pins have failed by the time pool level has reached elevation 222.5 feet, NGVD.

TABLE 4

TURNERS FALLS DAM OPERATING SUMMARY

Condition	Flow Rate (cfs)	Maximum Lower Pool Level (ft, NGVD)
1	Less than 12,000	185.0
2	12,000 to 30,000	186.5
3	30,000 to 65,000	186.5
4	65,000 to 126,000	
a. Peak flow expected to be less than 126,000		186.5
b. Peak flow expected to be greater than 126,000		181.5
5	Above 126,000	Varies from 181.5 at 126,000 cfs to 187.5 at 230,000 cfs

CLIMATOLOGY

The climate in the Connecticut River Basin varies considerably, depending upon elevations and locations relative to the coast. High elevations of the Green and White Mountain Ranges, for instance, have a marked influence on temperature, precipitation, and snowfall in northern and central areas. The basin lies in the path of prevailing westerlies and air masses moving predominantly from the interior of North America. Generally west to southwest airflow brings the hot dry weather responsible for occasional summer droughts. In winter, high pressure areas from Canada bring frigid air into the basin. The average annual temperature at Turners Falls, Massachusetts is about 48 °F. Table 5 presents a summary of temperatures for selected communities within the Connecticut River Basin.

Precipitation is moderate to heavy and well distributed throughout the year. The average annual precipitation ranges from approximately 37 inches in the main river valley to over 60 inches in the higher White and Green Mountains. Precipitation data for the basin is presented in Table 6. Annual runoff follows a pattern similar to the annual precipitation as it varies from 17 inches in lower elevations of the basin to more than 40 inches in high elevations of the White and Green Mountains . Precipitation in central and northern portions of the basin during winter is practically all in the form of snow (see Table 7). The average snowfall ranges from 50 to70 inches in the valley to well over 100 inches in the mountains. Water content of the snow in the Green and White Mountain areas reaches maximum about mid-March and can accumulate from 6 to over 10 inches in extreme upper limits of the basin and in higher elevations in the mountains. As a result of heavy snow accumulation, about 50 percent of the annual runoff occurs in the spring months of March, April and May.

The three general types of storms that cause precipitation over the basin are continental, coastal and thunderstorms. Continental storms originate over western and central portions of the United States and move generally in an easterly or northeasterly direction.

Tropical storms and hurricanes, the most severe of the coastal storms, originate in the South Atlantic or Caribbean Sea and usually move westerly, then northerly, and may possibly be deflected by high pressure zones to New England. Hurricanes have occurred in late summer and early fall. Extratropical coastal storms, generally occurring in the autumn, winter and spring months, originate near the mid- Atlantic States and travel northward along the coastline.

Thunderstorms, the third type, can be produced by local convective activity during warm humid summer days or associated with a frontal system moving across the basin.

TABLE 5

MONTHLY TEMPERATURES
(Degrees, Fahrenheit)

	HANOVER, NH El. 600 ft, NGVD 63 Years of Record (1926-1988)			KEENE, NH El. 480 ft, NGVD 63 Years of Record (1926-1988)			TURNERS FALLS, MA El. 190 ft, NGVD 30 Years of Record (1948-1977)			AMHERST, MA El. 150 ft, NVGD 63 Years of Record (1926-1988)		
Month	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum
January	18	-4	39	22	-2	41	24	2	41	23	0	41
February	21	-5	48	24	-5	44	25	6	43	26	0	47
March	31	12	56	34	15	58	34	18	51	35	18	57
April	44	26	65	46	28	66	47	30	64	47	28	67
May	56	37	76	57	35	77	58	38	76	59	38	77
June	65	47	83	66	47	85	67	51	86	66	49	85
July	70	53	88	70	50	89	71	55	89	71	54	87
August	68	51	85	68	48	85	69	51	86	69	52	86
September	59	42	79	61	41	81	62	44	82	62	43	80
October	48	31	71	50	30	73	52	34	71	51	32	72
November	37	21	51	39	20	55	40	26	56	41	25	57
December	23	4	40	26	7	44	28	10	44	28	10	46
ANNUAL	**45**	**31**	**59**	**47**	**31**	**62**	**48**	**34**	**63**	**48**	**34**	**62**

TABLE 6

MONTHLY PRECIPITATION RECORDS
(Mean Value in Inches)

	HANOVER, NH El. 600 ft, NGVD 63 Years of Record (1926-1988)	KEENE, NH El. 480 ft, NGVD 63 Years of Record (1926-1988)	TURNERS FALLS, MA El. 190 ft, NGVD 30 Years of Record (1948-1977)	AMHERST, MA El. 150 ft, NVGD 63 Years of Record (1926-1988)
January	2.73	3.01	3.21	3.15
February	2.38	2.65	3.10	2.82
March	2.74	3.15	3.51	3.46
April	2.90	3.24	3.75	3.60
May	3.43	3.62	3.70	3.67
June	3.10	3.60	3.65	3.94
July	3.73	3.59	3.39	3.74
August	3.30	3.48	3.93	3.69
September	3.30	3.30	3.29	3.74
October	2.93	2.99	3.13	3.09
November	3.60	3.79	4.03	3.85
December	2.99	3.32	4.00	3.51
ANNUAL	**37.41**	**39.81**	**42.72**	**42.38**

TABLE 7

MEAN MONTHLY SNOWFALL
(Depth in Inches)

	HANOVER, NH El. 600 ft, NGVD 63 Years of Record (1926-1988)	KEENE, NH El. 480 ft, NGVD 63 Years of Record (1926-1988)	TURNERS FALLS, MA El. 190 ft, NGVD 30 Years of Record (1948-1977)	AMHERST, MA El. 150 ft, NVGD 63 Years of Record (1926-1988)
January	19.19	16.64	13.90	12.38
February	17.14	14.73	16.06	11.64
March	12.46	11.85	9.88	7.55
April	2.70	2.77	0.77	1.73
May	0.16	0.08	0	0.02
June	0	0	0	0
July	0	0	0	0
August	0	0	0	0
September	0	0	0	0
October	0.20	0.05	0	0
November	4.79	3.48	1.31	2.32
December	17.03	14.14	9.47	9.20
ANNUAL	**76.16**	**65.53**	**56.20**	**45.17**

STREAMFLOW

Annual Runoff

Average annual streamflow for the basin is approximately 1.7 cfs per square mile of drainage area, equivalent to 22.5 inches of runoff or about 52 percent of the average annual precipitation. Runoff is fairly uniformly distributed throughout the year.

Streamflow Records

U.S. Geological Survey (USGS) discharge gages at Turners Falls, MA (drainage area = 7,163 square miles) and at Montague City, MA (drainage area = 7,860 square miles) were selected for updated analysis in this study. The selections were made due to proximity of the study area as well as long periods of record, ranging from 1916 to 1988 for Turners Falls and from 1904 to 1988 for Montague City. Other USGS gaging stations and locations with partial records were analyzed in the 1979 Corps report and information on those sites is presented in the following section.

Analysis of Data

Discharge frequency analyses were completed for selected USGS gaging stations and index sites for inclusion in the report, "Comprehensive Water and Related Land Resources Investigation: Connecticut River Basin," prepared in 1970. These stations were chosen due to their influence on peak discharges within the Connecticut Basin. Tabulations of natural peak discharge-frequency relationships (i.e., without Corps of Engineers flood control reservoirs) at gages on the Connecticut River are included in Table 8. Table 9 shows observed 1936 and 1938 flood data as would be reduced by the system at Corps reservoirs. In Table 9, note the 1936 and 1938 storms at the Vernon USGS gage produced observed floodflows having an estimated natural 1 percent (100-year event) and 4 percent (25-year event) chance of occurrence, respectively.

Modified discharge-frequency relationships, showing the impact of Corps flood control reservoirs, were developed in flood insurance studies completed for the towns of Gill and Northfield, Massachusetts in 1979 and 1980, respectively, and also in the 1970 Connecticut River Comprehensive Study. Results are presented in Table 10. The incorporation of Corps reservoirs has had a significant impact in controlling peak discharges and associated erosive potential. Now a 100-year modified flood flow at the Schell Bridge is equivalent to what was an approximate 30-year natural event.

Average daily discharge records at USGS gages located on the Connecticut River at Turners Falls and Montague City were analyzed for this study and the results are shown in Table 11. It can be seen that months with the highest average flows are March, April, and May, although floods can occur at any time of the year.

Records for the Turners Falls gage were further analyzed for two periods: 1916-1988 and 1969-1988. Table 12 and Plate 3 present information on the relationship between monthly mean, minimum, and maximum average daily flows for the two periods of record for the Turners Falls gage. The average daily discharge over the last 20 years is nearly 6 percent greater than the average

TABLE 8

NATURAL* PEAK DISCHARGE DATA FOR CONNECTICUT RIVER INDEX STATIONS

Location	EXCEEDANCE FREQUENCY					
	200-Year (0.5%) (cfs)	100-Year (1.0%) (cfs)	50-Year (2.0%) (cfs)	20-Year (5.0%) (cfs)	10-Year (10%) (cfs)	5-Year (20%) (cfs)
S. Newbury, VT (USGS Gage)	91,000	79,000	70,000	57,500	50,000	43,000
White River Junction, VT (USGS Gage)	150,000	130,000	111,000	89,000	74,500	62,000
Windsor, VT (Windsor Highway Bridge)	160,000	140,000	120,000	99,000	84,000	71,500
Bellows Falls, VT (N.E.P. Co. Dam)	178,000	157,000	138,000	114,000	99,000	84,000
Vernon, VT (USGS Gage)	199,000	176,000	153,000	128,000	110,000	94,000
E. Northfield, MA (Schell Bridge)	218,000	194,000	170,000	141,000	122,000	104,000
Montague City, MA (USGS Gage)	253,000	222,000	194,000	160,000	137,000	115,000
Northampton, MA (C. Coolidge Highway Bridge)	262,000	230,000	201,000	167,000	143,000	122,000
Thompsonville, CT (USGS Gage)	277,000	250,000	220,000	184,000	160,000	136,000
Middletown, CT (USGS Gage)	262,000	235,000	210,000	178,000	153,000	130,000

* Without the existing system of Corps flood control reservoirs

TABLE 9

CONNECTICUT RIVER BASIN
MAJOR FLOODS - EFFECT OF RESERVOIR SYSTEMS

Location	MARCH 1936 FLOOD				SEPTEMBER 1938 FLOOD			
	Observed Discharge	El.	Modified* Discharge	El.	Observed Discharge	El.	Modified* Discharge	El.
North Stratford Gage, NH	28,400	894.8	28,400	894.8	12,800	889.9	12,800	889.9
Wells River, VT	79,500**	418.6	79,500	418.6	44,000**	413.1	44,000	413.1
White River Junction, VT	120,000	354.1	115,000	353.3	82,400	347.7	78,500	347.0
North Walpole Gage, NH	166,500	258.8	134,700	252.8	118,500	249.4	92,600	243.8
Vernon Dam, VT	176,000	231.3	142,400	227.2	132,500	226.3	98,200	223.0
Schell Bridge, MA	192,600**	218.2	145,600	209.2	145,500**	209.1	106,800	202.1
Montague City Gage, MA	236,000	149.1	185,200	143.4	195,000	144.7	151,800	139.2
Holyoke Dam, MA	244,000	129.9	187,500	126.2	189,000	126.4	148,000	122.3
Thompsonville Gage, CT	282,000	55.1	211,600	51.6	236,000	52.9	189,200	50.6
Bodkin Rock Gage, CT	267,500	28.0	206,100	23.5	239,000	26.0	194,500	23.8

* Existing reservoirs include Union Village, North Hartland, North Springfield, Ball Mountain, Townshend, Surry Mountain, Otter Brook, Birch Hill, Tully, Barre Falls, Conant Brook, Knightville, Littleville, Sucker Brook, Mad River, Colebrook.

** Estimated Flow
All elevations in feet NGVD.

TABLE 10

MODIFIED* PEAK DISCHARGE DATA
AT SCHELL BRIDGE, NORTHFIELD, MA

EXCEEDANCE FREQUENCY			
500-Year 0.2% (cfs)	100-Year 1% (cfs)	50-Year 2% (cfs)	10-Year 1% (cfs)
196,300	151,700	133,100	95,400

* As modified by the existing system of Corps flood control reservoirs

TABLE 11

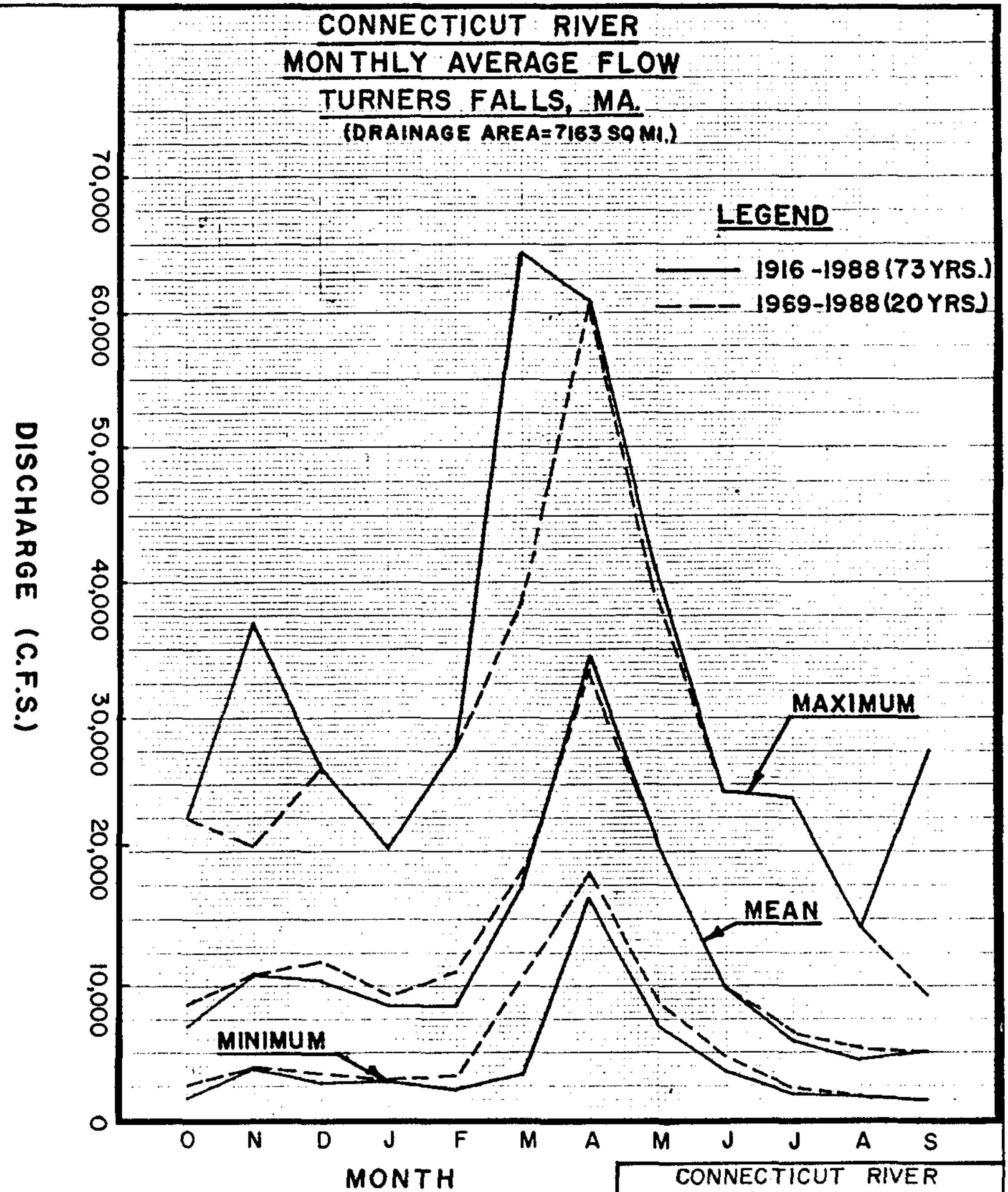
AVERAGE DAILY FLOW RATE
AT SELECTED STATIONS

	Connecticut River @ Montague City, MA (1905-1988) (D.A. = 7,860 sq. mi.)			Connecticut River @ Turners Falls, MA (1916-1988) (D.A. = 7,163 sq. mi.)		
	Flow (cfs)			Flow (cfs)		
Month	Mean	Minimum	Maximum	Mean	Minimum	Maximum
January	10,640	2,732	23,890	8,480	2,876	20,360
February	10,260	2,086	33,650	8,485	2,224	27,590
March	20,520	4,316	71,920	17,390	3,423	64,400
April	39,100	18,620	66,290	34,580	16,420	61,000
May	23,650	8,080	47,000	20,280	6,954	41,080
June	11,360	4,270	30,730	9,719	3,485	24,510
July	6,555	2,250	25,680	5,756	1,907	23,960
August	5,375	2,412	18,150	4,442	1,886	14,590
September	5,935	1,834	32,660	4,863	1,561	27,700
October	8,265	1,829	25,750	6,939	1,671	22,480
November	12,040	2,053	42,270	10,650	3,815	36,810
December	12,260	2,810	31,710	10,370	2,746	26,390
ANNUAL	**13,810**	**6,768**	**20,680**	**11,840**	**7,714**	**17,420**

TABLE 12

AVERAGE DAILY FLOW RATE
CONNECTICUT RIVER AT TURNERS FALLS DAM

	Period of Record (1916-1988)			Period of Record (1969-1988)		
	Flow (cfs)			Flow (cfs)		
Month	Mean	Minimum	Maximum	Mean	Minimum	Maximum
January	8,480	2,876	20,360	9,084	3,049	20,360
February	8,485	2,224	27,590	11,140	3,166	20,150
March	17,390	3,423	64,400	18,720	10,220	38,600
April	34,580	16,420	61,000	33,340	18,240	60,720
May	20,280	6,954	41,080	20,620	8,785	39,360
June	9,719	3,485	24,510	9,802	4,743	24,510
July	5,756	1,907	23,960	6,387	2,345	23,960
August	4,442	1,886	14,590	5,216	1,937	14,590
September	4,863	1,561	27,700	5,092	1,618	9,299
October	6,939	1,681	22,480	8,573	2,597	22,480
November	10,650	3,815	36,810	10,750	3,815	20,410
December	10,370	2,746	26,390	11,730	3,385	26,390
ANNUAL	**11,840**	**7,714**	**17,420**	**12,520**	**8,136**	**17,170**



CONNECTICUT RIVER
STREAMBANK EROSION STUDY

MONTHLY AVERAGE FLOW

HYD. & WQ. BR. NOV. 1990

PLATE 3

daily discharge for the period of record for the Turners Falls gage. Maximum daily discharges are also shown to be the highest on record for six months of the year and very near the record for the remaining months; with exceptions being March and September when monthly record floods occurred in 1936 and 1938, respectively. Overall, this data indicates a slightly greater erosive potential for riverflow from 1969-1988.

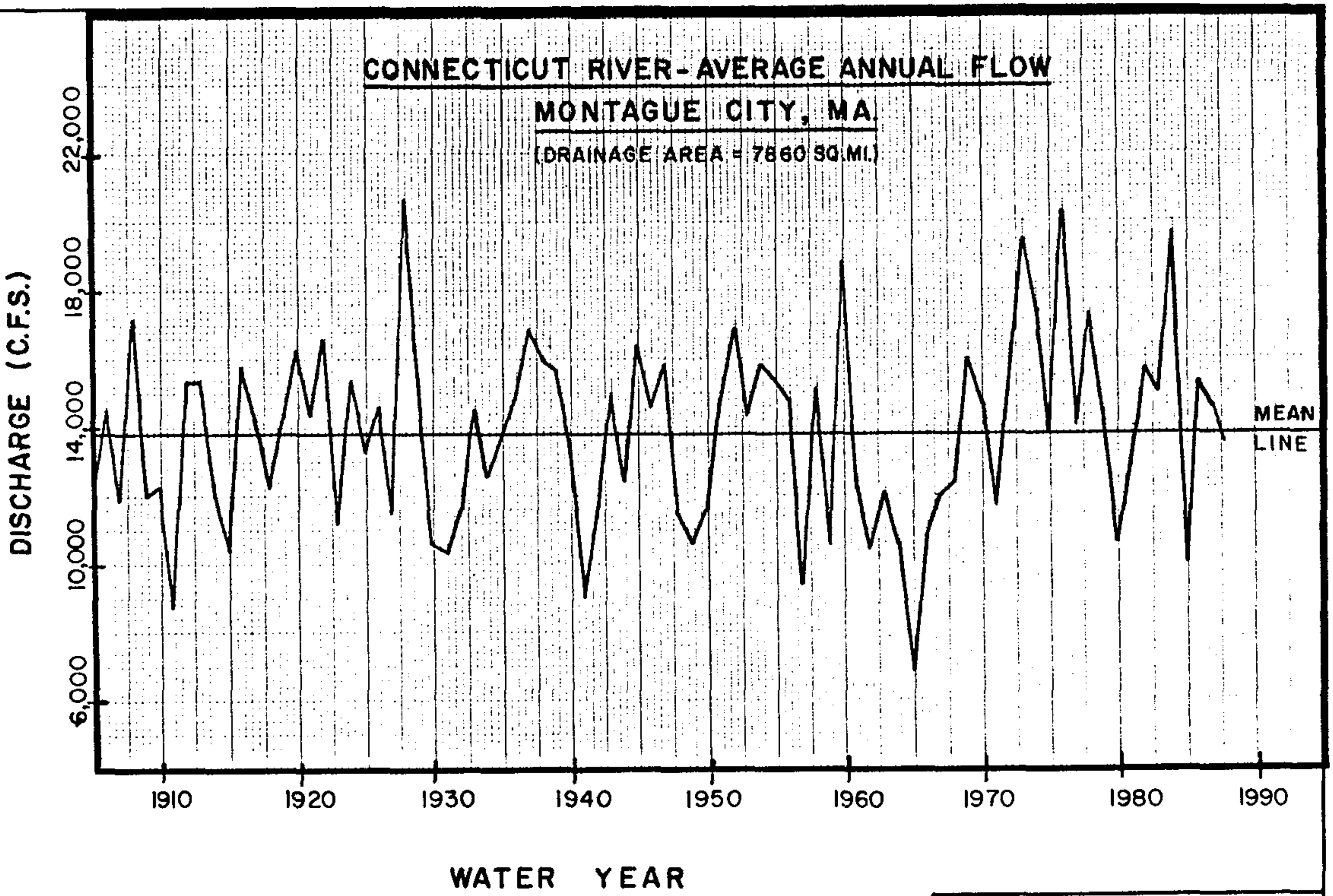
Plates 4 and 5 show a plot of average annual flow at Montague City and Turners Falls, respectively. From these plots, it can be seen that discharges were near or higher than the mean discharge levels on all but four of the last 20 years, indicating that erosive energy available in the Connecticut River due to flow in this area was generally above average for that period. This may not be thoroughly conclusive based on display of peak annual discharges for Turners Falls Dam shown in Plate 6 and Table 13. If most erosion occurs only during major floods, then the last 20 years have had only one of the top ten events for the 73 year period of record. However, the May 1984 and April 1987 events are the greatest of record dating back to 1960, and the greatest since completing the Corp's upstream system of flood control reservoirs.

One further analysis was completed comparing the frequency of exceedance for average daily discharges at Turners Falls for the entire period of record to that of the last 20 years (results are shown in Plate 7). There were no apparent differences in flows between the monitoring periods for discharges above 20,000 cfs. However, average daily flows in the lower range of discharges for the last 20 years are higher than those of the period of record, i.e., 4,200 cfs versus 3,700 cfs at an 80 percent exceedance frequency and 13,000 cfs versus 12,000 cfs at a 30 percent exceedance frequency. This analysis shows that with an increase in day-to-day flow of up to 14 percent that the last 20 years may have had a more significant erosive impact than a typical 20-year span in the entire 73-year period of record.

HYDRAULIC ANALYSES

Mathematical unsteady flow simulations of Turners Falls Reservoir for several different flow regimes were evaluated in the 1979 Corps report. These simulations provided estimated average flow conditions which were used in that report to identify causes of erosion. The periods evaluated occurred during 1974 and 1976 and flow rates varied from 6,600 to 77,000 cfs. Although applying specifically to flows in the periods 1974 and 1976, these conditions can be used to extrapolate erosion conditions for similar flow regimes.

The 17-22 July 1976 low flow period had average daily measurements at the Turners Falls gage (drainage area = 7,163 sq. mi.) ranging between 3,500 and 6,600 cfs. Limited generation or pumping occurred at Northfield Mountain simply because usable water was not available. The fastest river velocities were attained not through natural stream flow but were associated with the pumped storage hydroelectric facility. Maximum average river velocities during pumping were less than 0.5 fps while during generation maximum average velocities were nearly 3 fps in the area adjacent to the tailrace, the location of the fastest velocities in the pool. This velocity is considered quite small in comparison to other hydrologic conditions that occurred within the pool during high flow periods. Localized eddy action was observed in the tailrace area as predicted by the physical

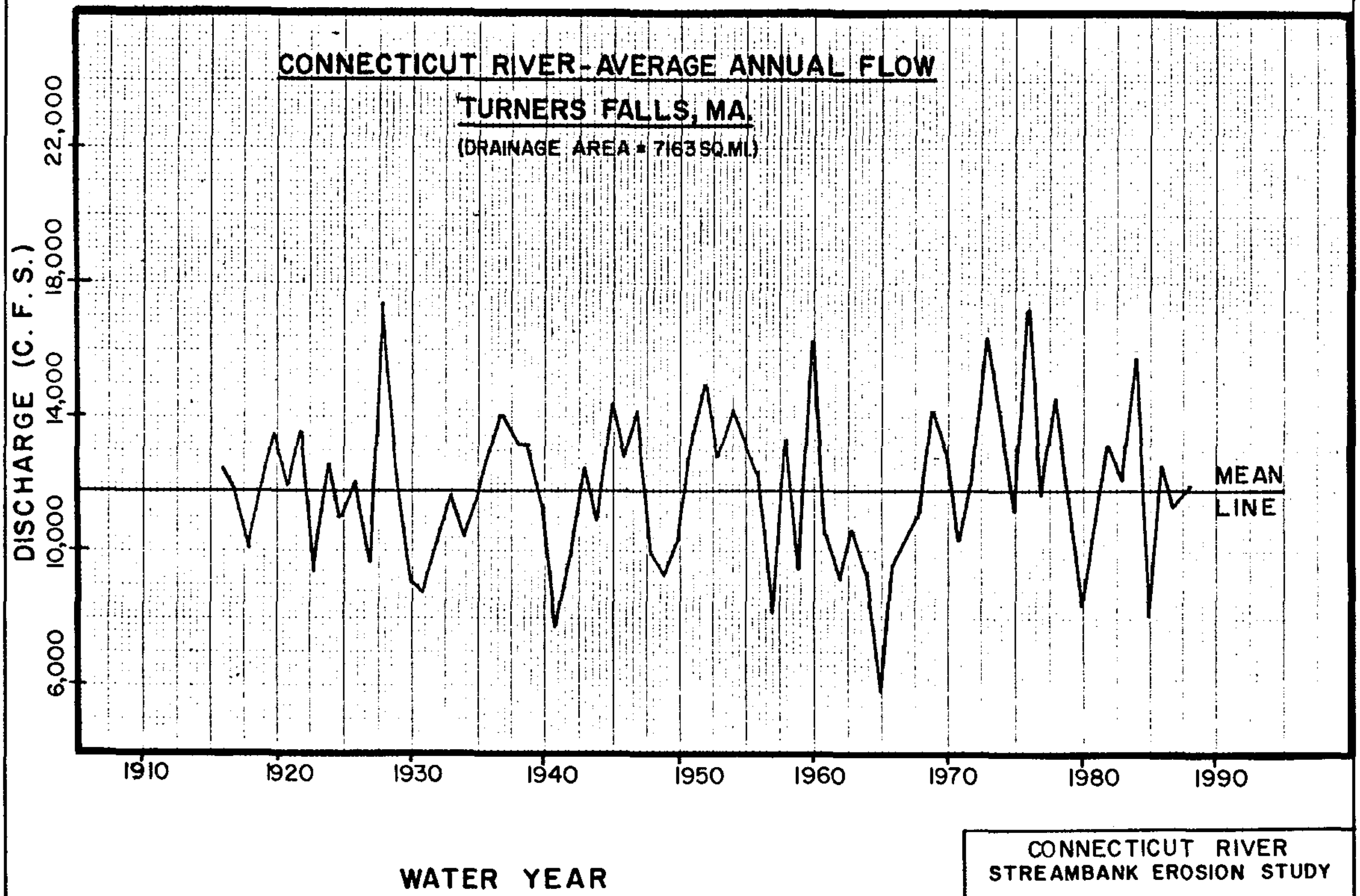


CONNECTICUT RIVER
STREAMBANK EROSION STUDY

MONTAGUE CITY, MA.
AVERAGE ANNUAL FLOW

HYD. & WQ.BR. NOV. 1990

PLATE 4

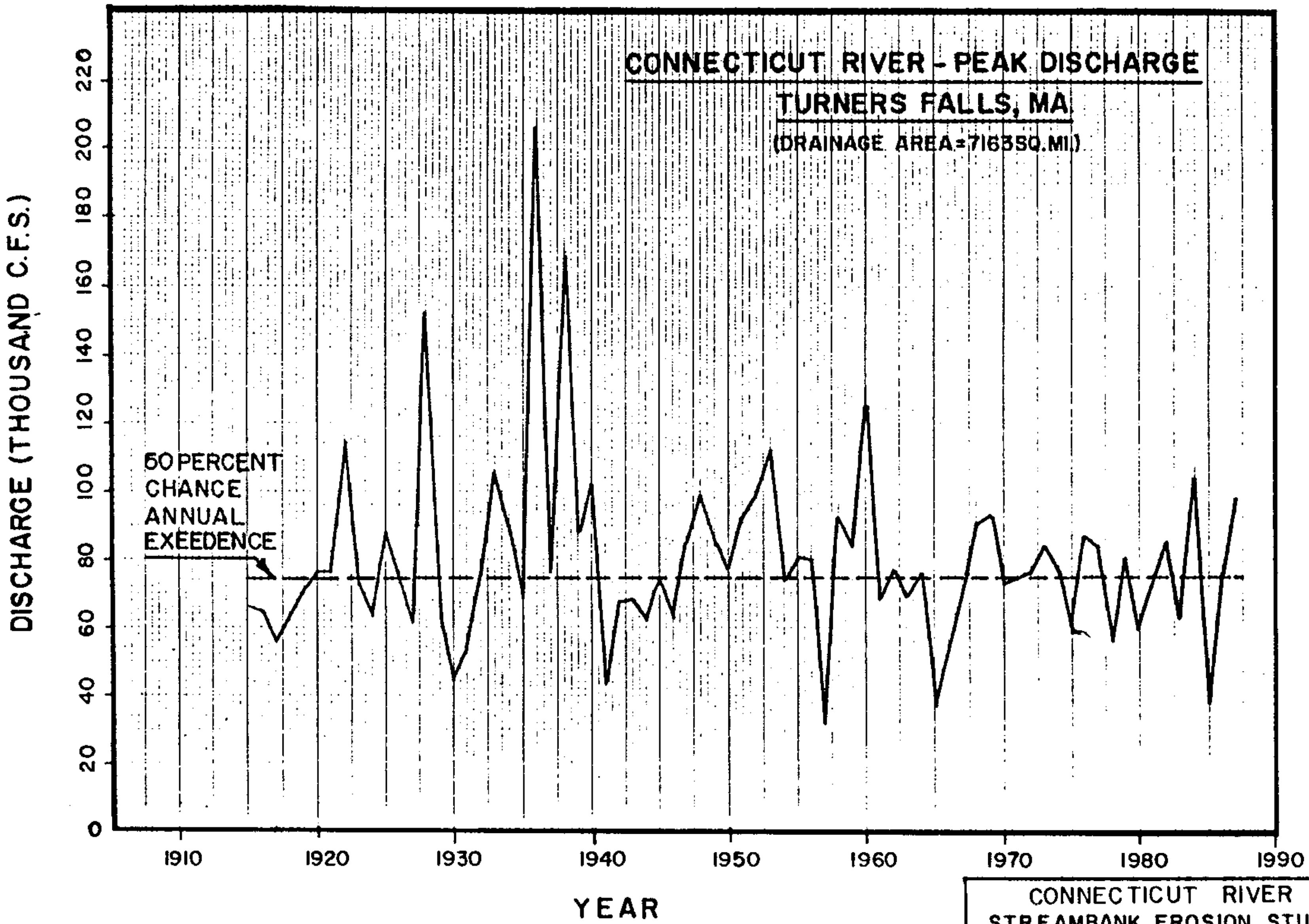


CONNECTICUT RIVER
STREAMBANK EROSION STUDY

TURNERS FALLS, MA.
AVERAGE ANNUAL FLOW

HYD. & WQ. BR. NOV. 1990

PLATE 5



CONNECTICUT RIVER
STREAMBANK EROSION STUDY

TURNERS FALLS, MA.
PEAK DISCHARGE

HYD. & WQ. BR. NOV. 1990

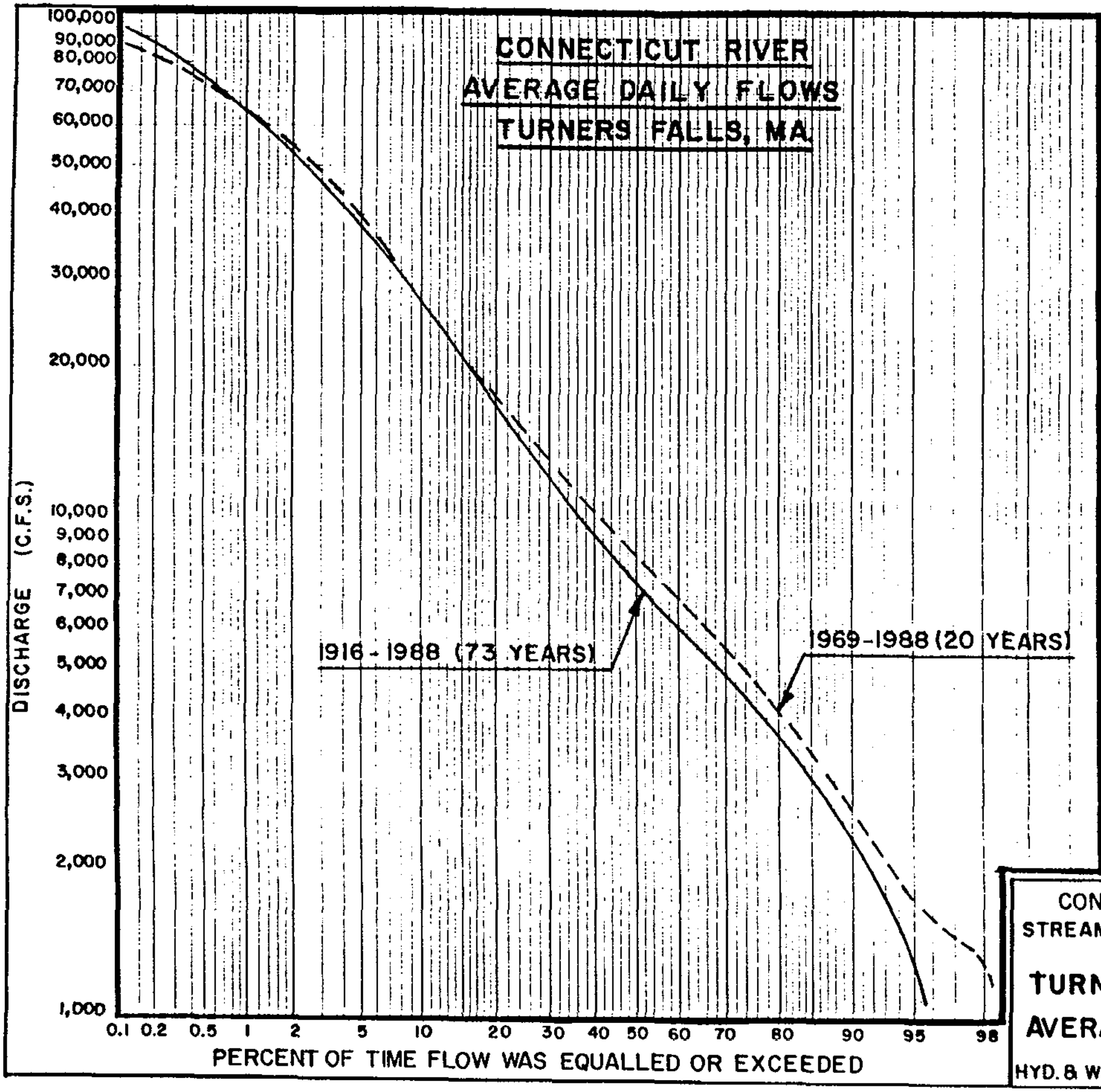
PLATE 6

TABLE 13

TURNERS FALLS DAM
PEAK FLOW EVENTS 1969-1988
(Drainage Area = 7,163 sq. mi.)

Date	Flow (cfs)
April 20, 1969	92,100
April 26, 1970	71,200
May 5, 1971	72,700
May 5, 1972	75,400
March 18, 1973	83,300
December 22, 1973	74,700
April 21, 1975	59,300
April 3, 1976	85,700
March 15, 1977	82,400
October 19, 1977	54,800
March 26, 1979	78,500
April 11, 1980	57,600
February 26, 1981	70,100
April 19, 1982	82,600
May 4, 1983	61,700
May 31, 1984*	103,000
March 13, 1985	36,500
April 1, 1986	75,200
April 1, 1987**	97,400

* Ninth highest since 1915
** Twelfth highest since 1915



CONNECTICUT RIVER
STREAMBANK EROSION STUDY

TURNERS FALLS, MA.
AVERAGE DAILY FLOW

HYD. & WQ.BR. NOV.1990

PLATE 7

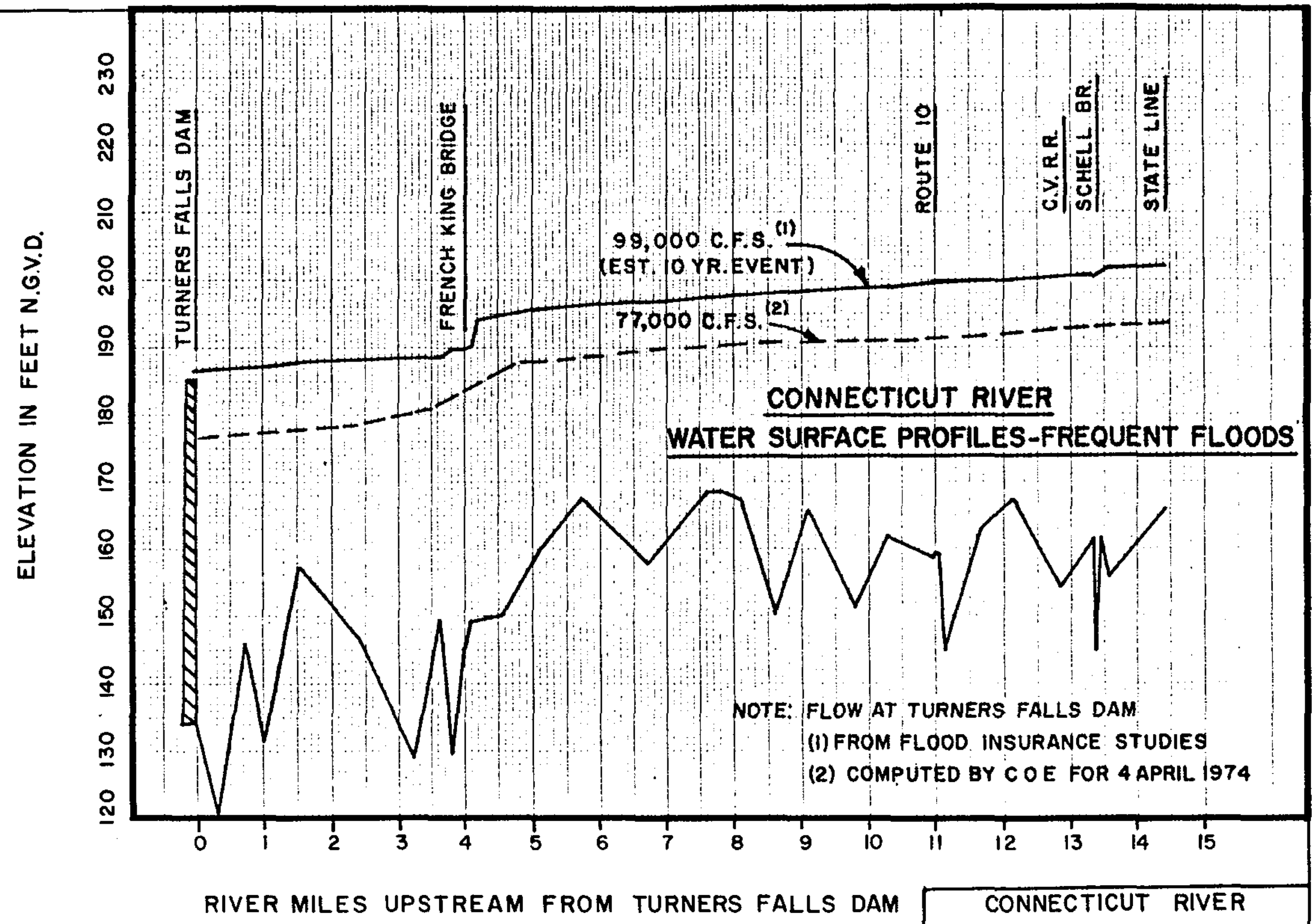
model for the design at the Northfield project.

The 2-7 September 1974 normal to moderate flow period (average flows ranged from 4,100 to 13,200 cfs at Turners Falls Dam) was generally similar to the previous low flow time. Average velocities were slightly higher with a maximum average velocity of 3.12 fps being calculated during power generation periods. During pumping operations maximum average velocities downstream and upstream of the Northfield tailrace were 0.70 and 0.61 fps, respectively. These velocities are not associated with scour erosion but indicate that eddy currents and other patterns likely formed in the tailrace. A maximum pool fluctuation of over 5 feet was observed on 3 September. During this period, the pool in general experienced relatively large scale fluctuations.

The 3-8 April 1974 typical spring runoff period (average Turners Fall Dam flows ranged from 11,900 to 77,000 cfs) was also examined. During this time interval the Turners Falls and Vernon Dams operated basically on a run-of-the-river basis, therefore, their effect on flows was minimal. The Northfield plant had the most water available at this time, so considerable water was pumped. Generation also occurred but at lesser flow rates since it was desirable to minimize releases to Turners Falls pool during the freshet. Maximum average velocities of 3.26 fps occurred during times of heavy riverine discharge. The largest annual fluctuation in pool elevation occurs during the typical spring event. At this particular time, the water elevation at Northfield Mountain increased from 179.3 feet NGVD at 0600 hours on 3 April to approximately 190.4 feet NGVD at 1200 hours on 6 April.

Flood profiles have been developed from backwater analyses completed in 1979 and 1980 for flood insurance studies of the towns of Gill and Northfield, Massachusetts, respectively. Events analyzed included 10, 50, 100, and 500-year frequencies with flows at Turners Falls Dam ranging from 99,000 to 207,000 cfs. These profiles are shown on Plates 8 and 9. In addition, a flood profile for the typical maximum discharge of 4 April 1976 (77,000 cfs) was developed during the 1979 Corps study and is shown on Plate 8. Most locations of the river's constrictions are labelled on both plates. A constriction at the French King Bridge provides the most control during high riverine flows. Water surface changes from as little as 8 feet to as much as 20 feet within a 1.5 mile stretch near the French King Bridge during flow rates varying from 77,000 to 207,000 cfs.

Average channel velocities in the Turners Falls pool at various locations for each flood profile within the Gill and Northfield flood insurance studies were extracted from backwater analyses and are presented in Table 14. Average velocities for a 10-year frequency event range from 2.6 to 14.5 fps and are, in general, much more significant than those occurring during power and generation cycles at the Northfield Mountain Pumped Storage Project. Local point velocities may be somewhat higher than average channel velocities presented in the table. Overall, considerable erosion would be expected for floods of this magnitude.

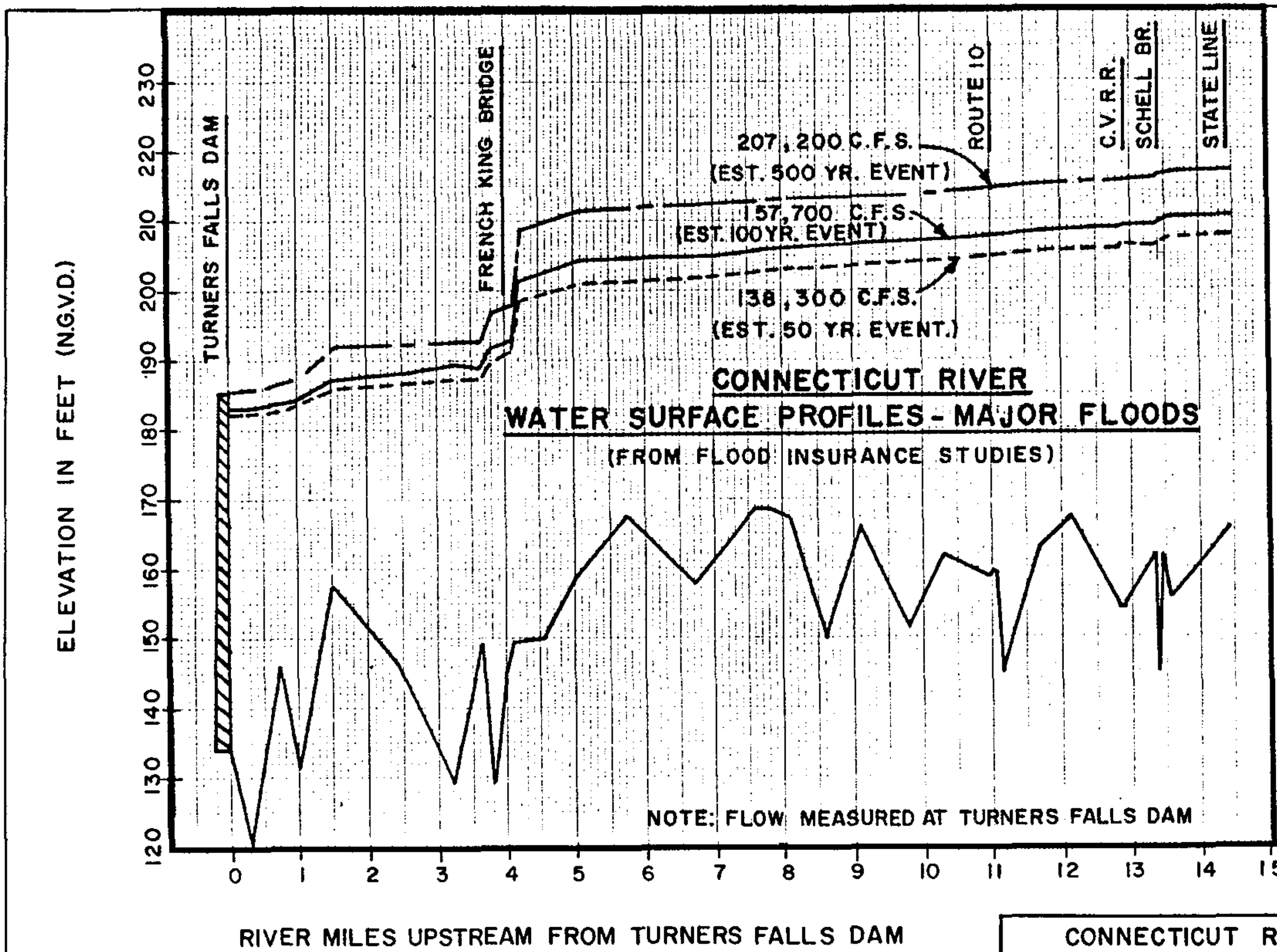


CONNECTICUT RIVER
STREAMBANK EROSION STUDY

WATER SURFACE PROFILES
FREQUENT FLOODS

HYD. & WQ. BR. NOV. 1990

PLATE 8



CONNECTICUT RIVER
STREAMBANK EROSION STUDY

WATER SURFACE PROFILES
MAJOR FLOODS

HYD. & WQ. BR. NOV. 1990

PLATE 9

TABLE 14

TURNERS FALLS RESERVOIR
AVERAGE CHANNEL VELOCITY (FPS)

River* Mile	10-Year 99,000 cfs	50-Year 138,300 cfs	10-Year 157,700 cfs	500-Year 207,200 cfs
0.30	4.5	7.0	7.8	9.7
0.76	3.3	5.7	6.1	6.9
1.02	7.0	10.9	12.0	14.6
1.56	2.6	4.0	4.2	4.6
2.42	4.9	7.2	7.9	9.2
3.25	4.2	6.0	6.6	7.8
3.65	9.0	13.1	14.1	16.4
3.82	3.7	5.1	5.5	6.6
4.00	7.9	10.9	11.6	13.0
4.12	14.5	19.8	21.2	23.7
4.24	8.0	9.9	10.3	11.3
4.58	7.1	8.6	9.1	10.0
5.07	4.5	5.1	5.1	5.1
5.75	3.8	4.4	4.4	4.4
6.14	4.5	5.3	5.3	5.2
6.71	6.0	7.3	7.5	7.4
7.65	3.8	4.4	4.6	4.9
7.89	3.7	4.1	4.1	4.1
8.12	3.7	4.2	4.3	4.3
8.61	5.7	6.4	6.5	6.3
9.14	4.3	4.9	5.0	5.2
9.81	5.0	5.8	6.0	6.3
10.31	6.1	6.7	6.5	6.1
10.97	4.0	4.2	4.0	3.8
11.00	5.1	6.1	6.5	7.2
11.17	5.7	6.6	6.7	6.5
11.69	4.9	5.4	5.3	5.0
12.15	4.6	5.1	5.1	5.0
12.85	5.2	6.1	6.3	6.4
12.87	5.1	6.1	6.4	7.0
13.37	7.9	8.9	8.9	8.6
13.60	3.8	4.4	4.6	4.9
13.96	4.6	5.0	5.1	5.1
14.46	4.3	5.0	5.2	5.5

* Upstream from Turners Falls Dam

LOCATION OF EROSION SITES WITHIN THE STUDY AREA

General

An evaluation of current erosion sites within the 14-mile Massachusetts portion of Turners Falls pool was completed during this study to determine progression of riverbank erosion since the 1979 study. In all, 22 erosion sites were identified during the field investigation in June 1990; an increase of 9 sites over that identified in the 1979 report. A summary of the June 1990 field trip, classifying location and characteristics of the sites, is presented in Table 15. The location of active erosion sites for the current study and the 1979 investigation are shown on Plates 10 to 13 and Plates 14 to 17, respectively. The field investigation was conducted by boat, similar to that done for the 1979 report, although some easily accessible areas were also viewed from land.

Comparison With the 1979 Report

Over one-half of the erosion sites are at the same general location as those identified during the earlier report. Two former sites are no longer included: No. 251 has been protected through riprapping as part of Northeast Utilities' effort to reduce shoreline damage, and No. 201 showed little sign of erosion during the June 1990 field visit. The remainder of the former sites, however, show signs of continued erosion and lengthening. The total estimated shoreline length currently undergoing some form of active erosion, based on the June 1990 field visit, is approximately 47,000 linear feet or 32 percent of the 148,000 linear feet of shoreline within Massachusetts in Turners Falls pool. This is an approximate threefold increase over that estimated as part of the 1979 report (estimated shoreline length undergoing some form of active erosion during September 1978 was 17,000 linear feet). Although there may be some differences in the simplified process of active erosion site identification and measurement between the June 1990 and September 1978 field visits, this difference should not significantly affect the overall conclusion, i.e., forces have significantly increased erosion within the pool in a 12-year period (1978 to 1990).

Site Classification

To provide some continuity with the 1979 report, each erosion site was evaluated according to five classifications: bank height, erosion type, bank location, soil type, and vegetation. Classification criteria for each category are described below.

Bank Height. Height of the eroded banks are divided into low (less than 15 feet) and high (greater than 15 feet). Majority of the sites investigated were low banks.

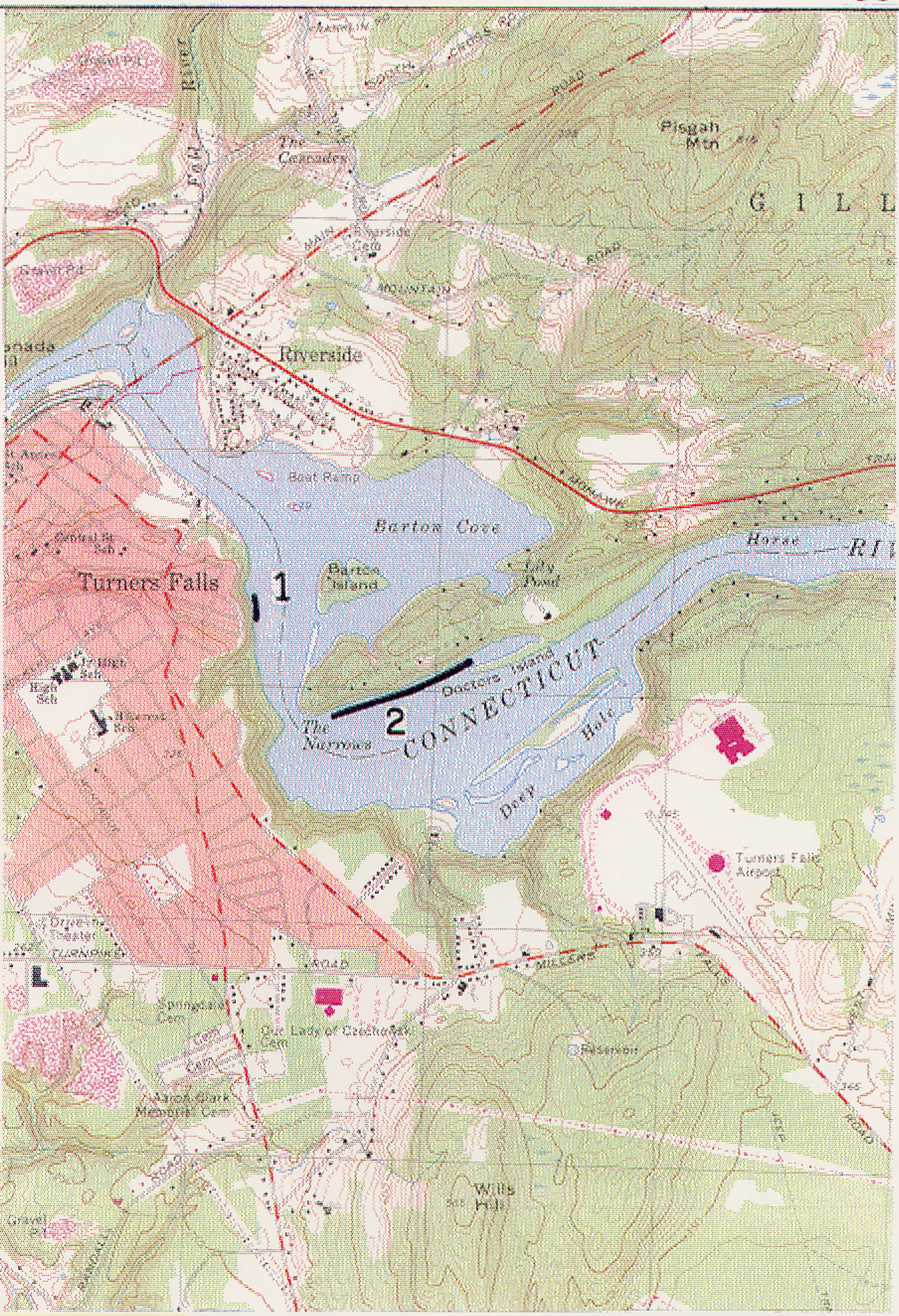
Erosion Type. This group was divided into three subgroups according to appearance of the erosion: mass wasting, sloughing, and undercutting. A pictorial representation of each subgroup is shown in Plates 18 through 20. Most erosion in the pool area was the sloughing variety or a com bination sloughing-mass wasting form. Although only a small portion displayed evidence of failure through undercutting, almost the entire reach where upper bank erosion occurred

TABLE 15

TURNERS FALLS RESERVOIR
CLASSIFICATION OF BANK EROSION SITES

Site*	River**	Bank Height		Erosion Type			Bank Location	Soil Type		Vegetation	
No.	Mile	Low <15'	High >15'	Sloughing	Mass Wasting	Under Cutting	Bend (B) or Straight (S)	Noncohesive	Stratified	Vegt'd	Barren
1	0.8	X		X			S	X		X	
2 (250)	1.4		X	X			S	X			X
3 (251)	4.6	X					B OUTER	X		X	
4	4.7		X	X			B INNER	X		X	
5	5.1		X	X			B OUTER	X		X	
6 (252)	5.5	X		X		X	B INNER		X		X
7 (202)	6.7	X		X	X		B INNER		X		X
8 (203)	7.5	X			X		S	X		X	
9 (255,256)	7.9		X	X	X	X	S		X		X
10 (257)	8.9	X		X			S		X		X
11	9.9	X		X			B OUTER		X	X	
12	10.7	X		X			S		X		X
13 (259)	11.1	X		X			B OUTER	X		X	
14	11.6	X			X		S	X			X
15	12.4		X	X	X		S		X		X
16	13.3		X	X		X	B INNER		X		X
17	12.9	X		X		X	B OUTER		X		X
18	11.4		X	X	X		S		X		X
19 (205)	11.0		X	X			S	X			X
20	10.6			X	X		B OUTER		X		X
21 (204)	9.8	X		X	X		B INNER		X	X	
22	8.9	X		X	X		B INNER	X			X
	Number	13	8	19	9	4	10S,6BO,6BI	10	12	8	14
	Percentage	62	38	59	28	13	45,27,28	45	55	36	64

* Former site no.s from 1979 Corps report in parentheses
** Upstream from Turners Falls Dam



CONTOUR INTERVAL 10 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

SCALE 1:24 000

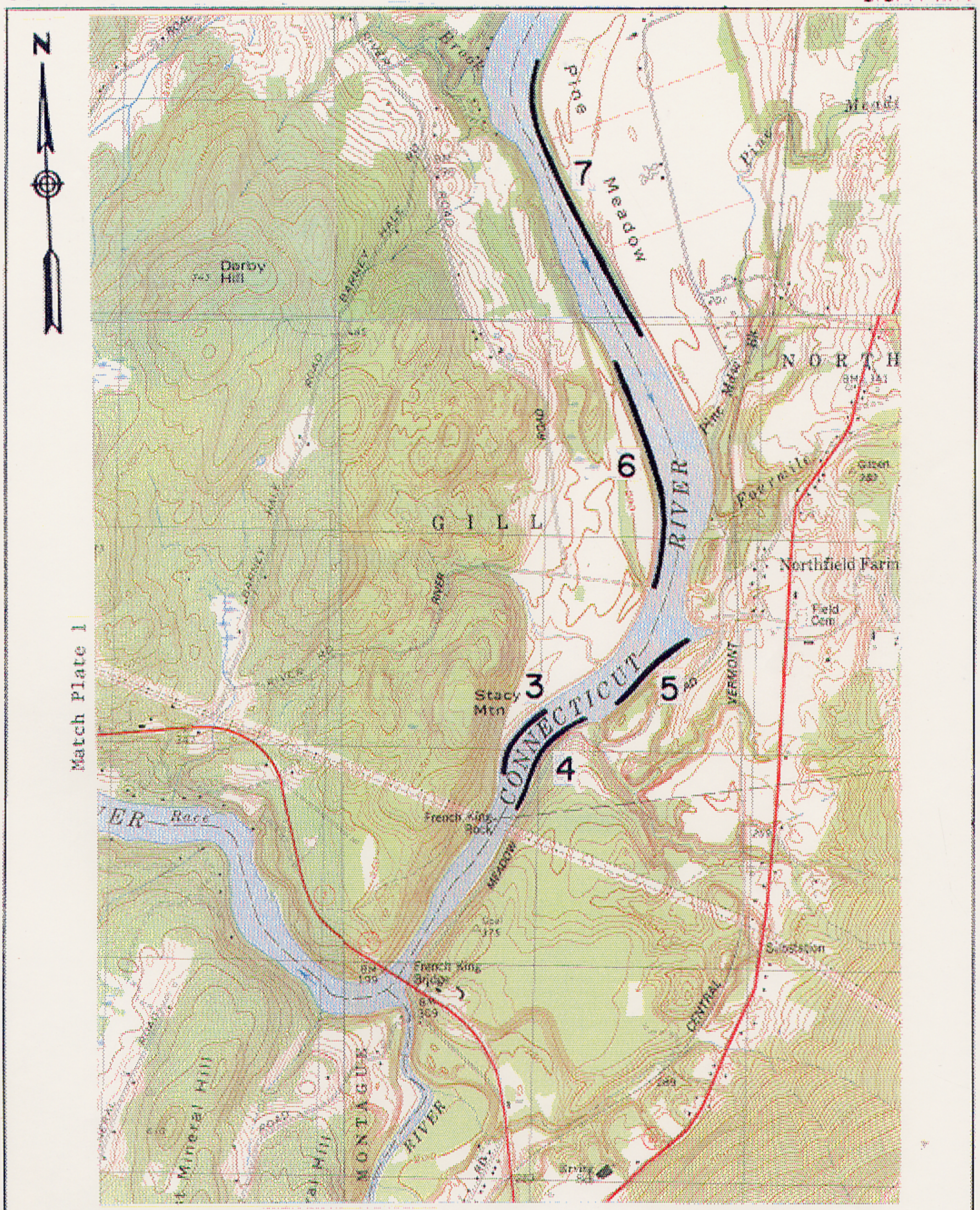
1000 0 1000 2000 3000 FEET

Denotes Eroded Bank

Connecticut River
Turners Falls to State Line, MA
General Investigation Study

EROSION SITE IDENTIFICATION

PLATE 10



CONTOUR INTERVAL 10 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

SCALE 1:25 000

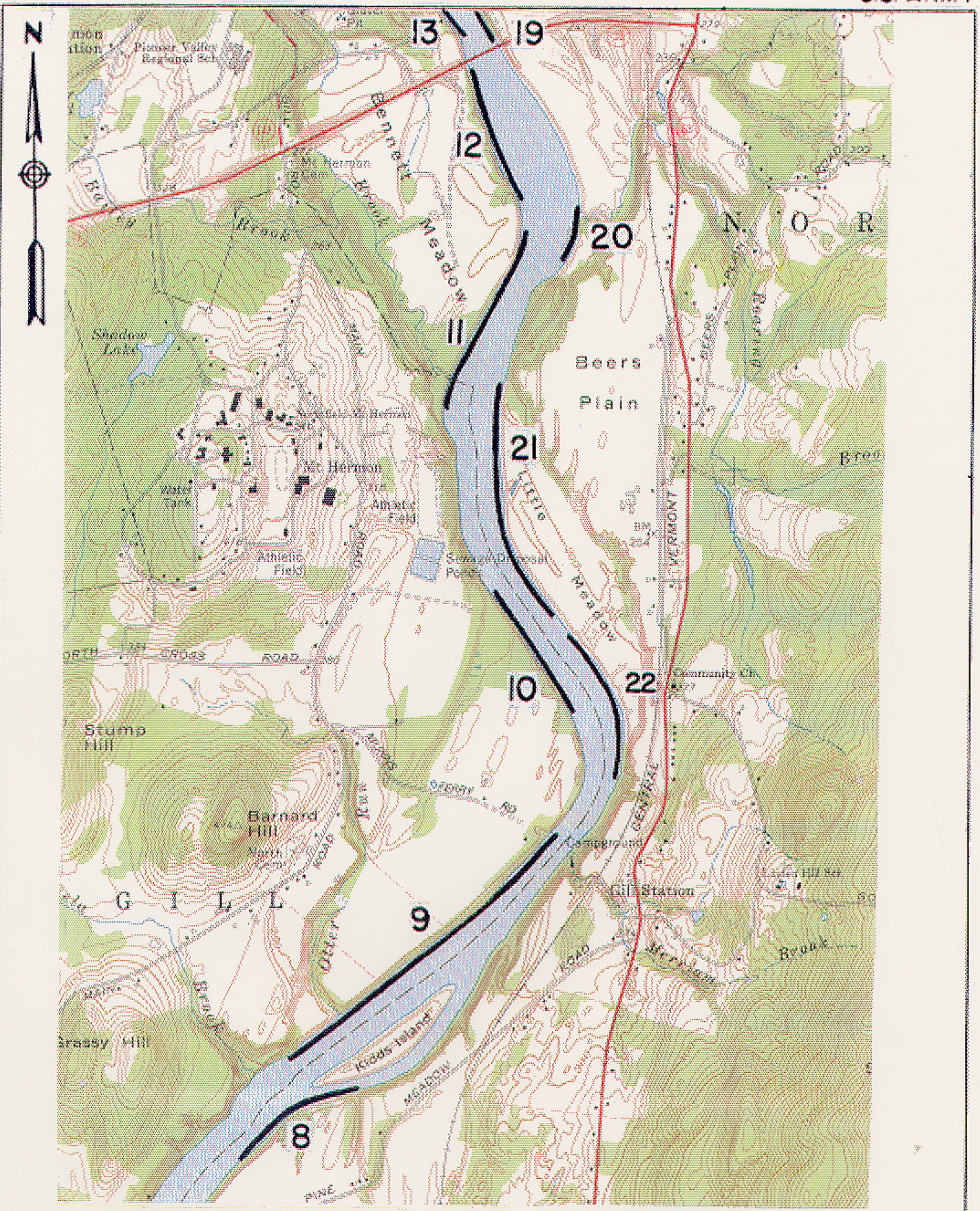
1000 0 1000 2000 3000 FEET

Denotes Eroded Bank

Connecticut River
Turners Falls to State Line, MA
General Investigation Study

EROSION SITE IDENTIFICATION

PLATE 11



CONTOUR INTERVAL 10 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

SCALE 1:25 000

1000 0 1000 2000 3000 FEET

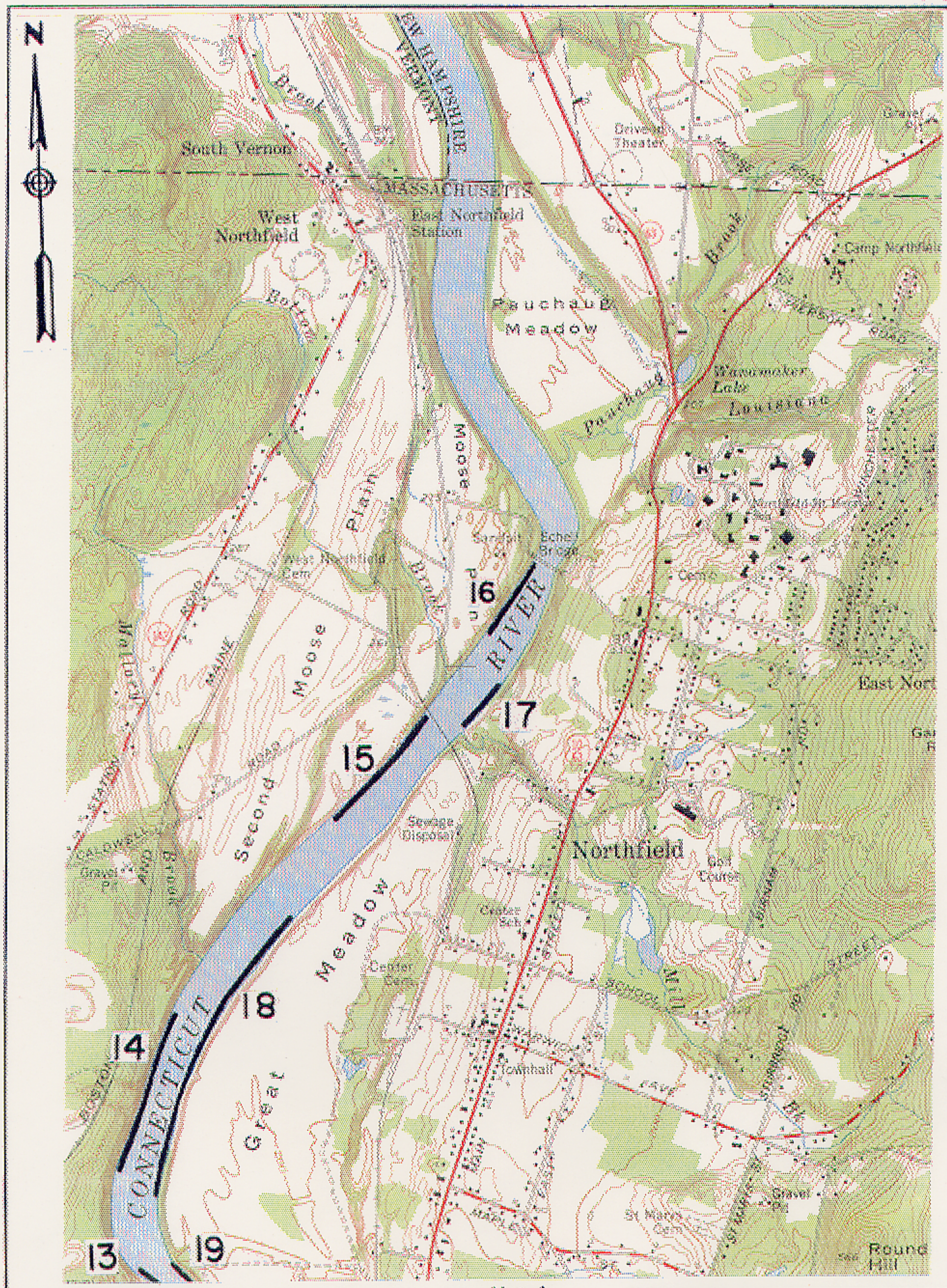
Match
Plate 2

Denotes Eroded Bank

Connecticut River
Turners Falls to State Line, MA
General Investigation Study

EROSION SITE IDENTIFICATION

PLATE 12



CONTOUR INTERVAL 10 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

SCALE 1:25 000

1000 0 1000 2000 3000 FEET

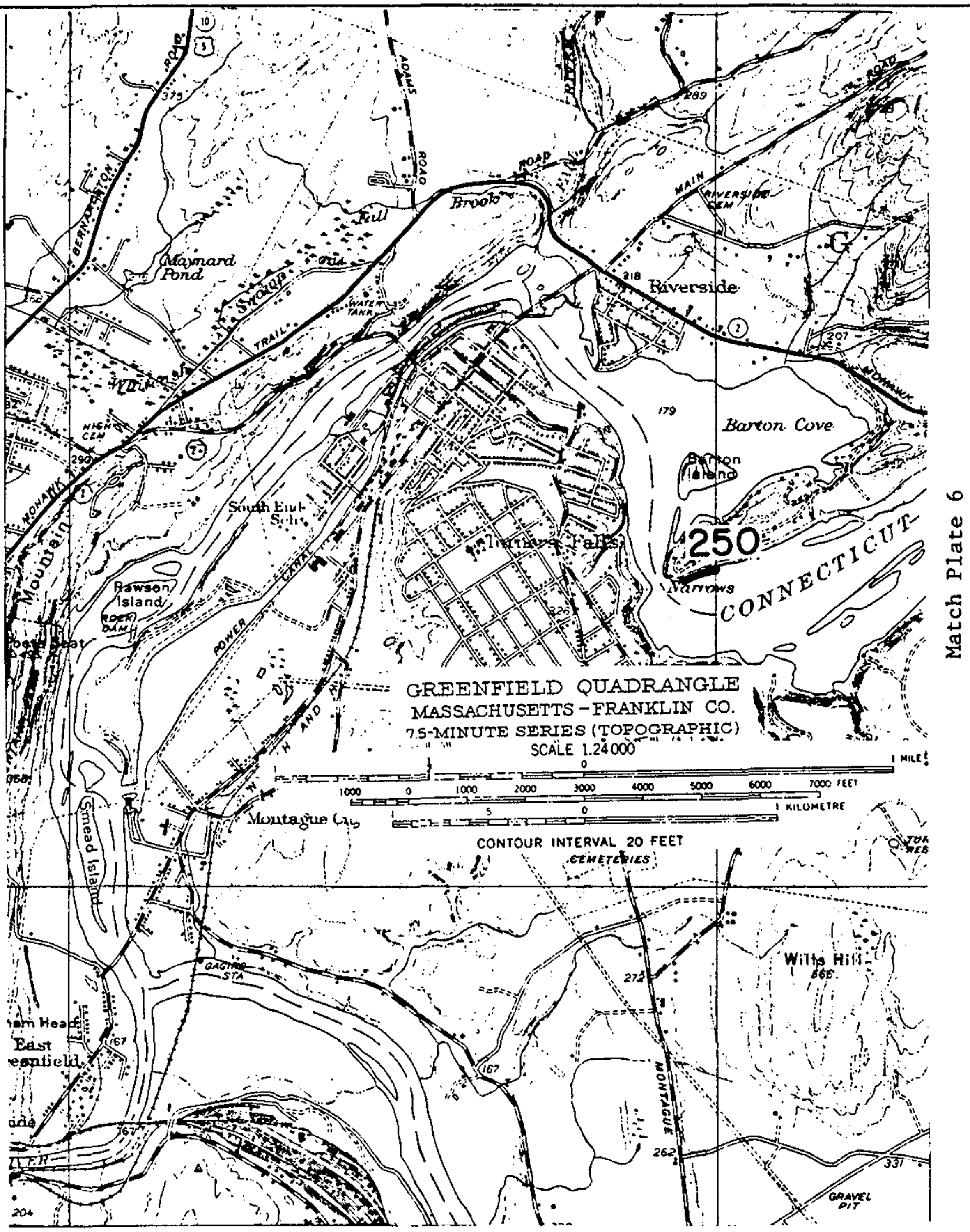
Denotes Eroded Bank

Match Plate 3

Connecticut River
Turners Falls to State Line, MA
General Investigation Study

EROSION SITE IDENTIFICATION

PLATE 13



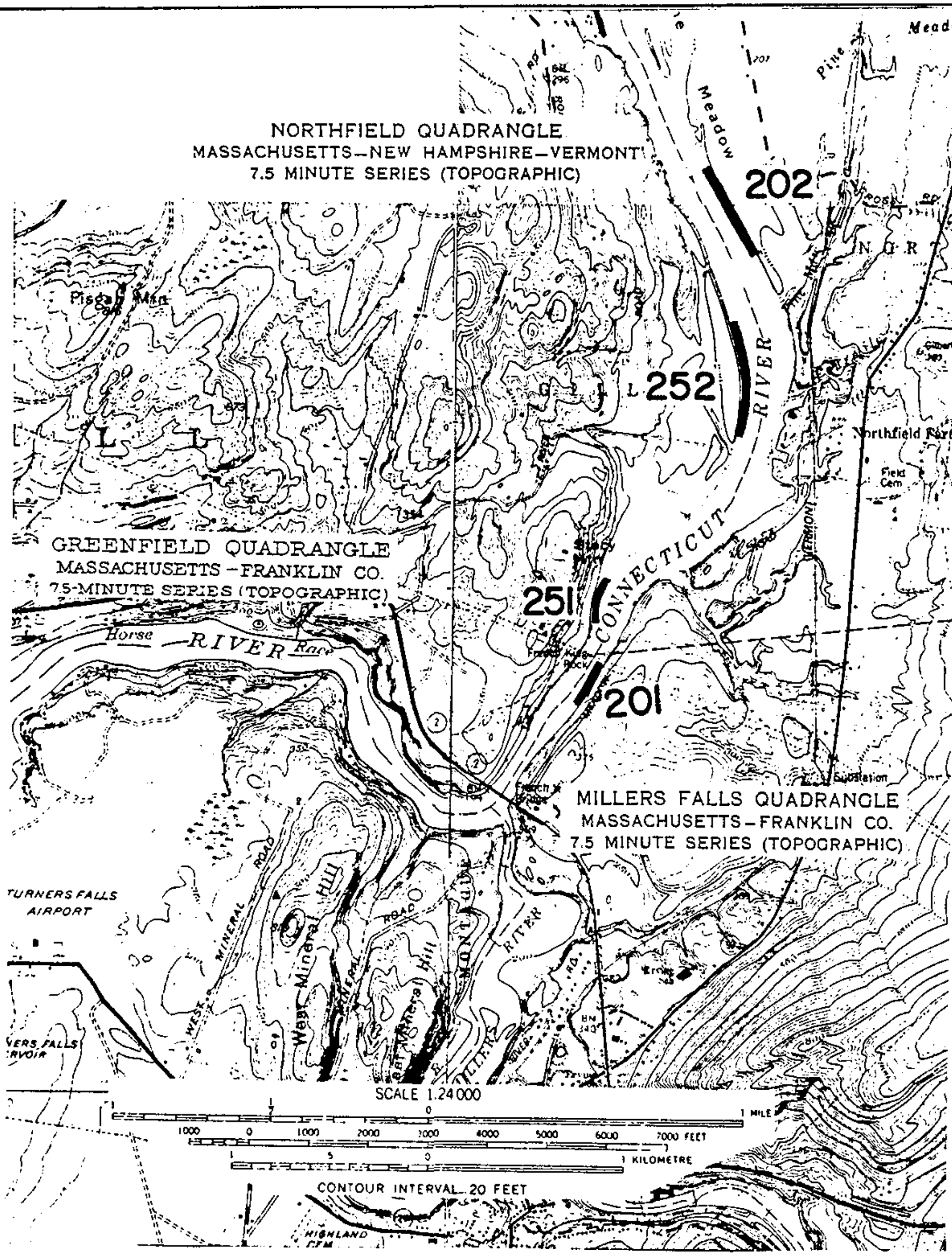
Denotes Eroded Bank, 1979

Connecticut River
Turners Falls to State Line, MA
General Investigation Study

EROSION SITES IDENTIFIED
IN 1979 REPORT

PLATE 14

Match Plate 5

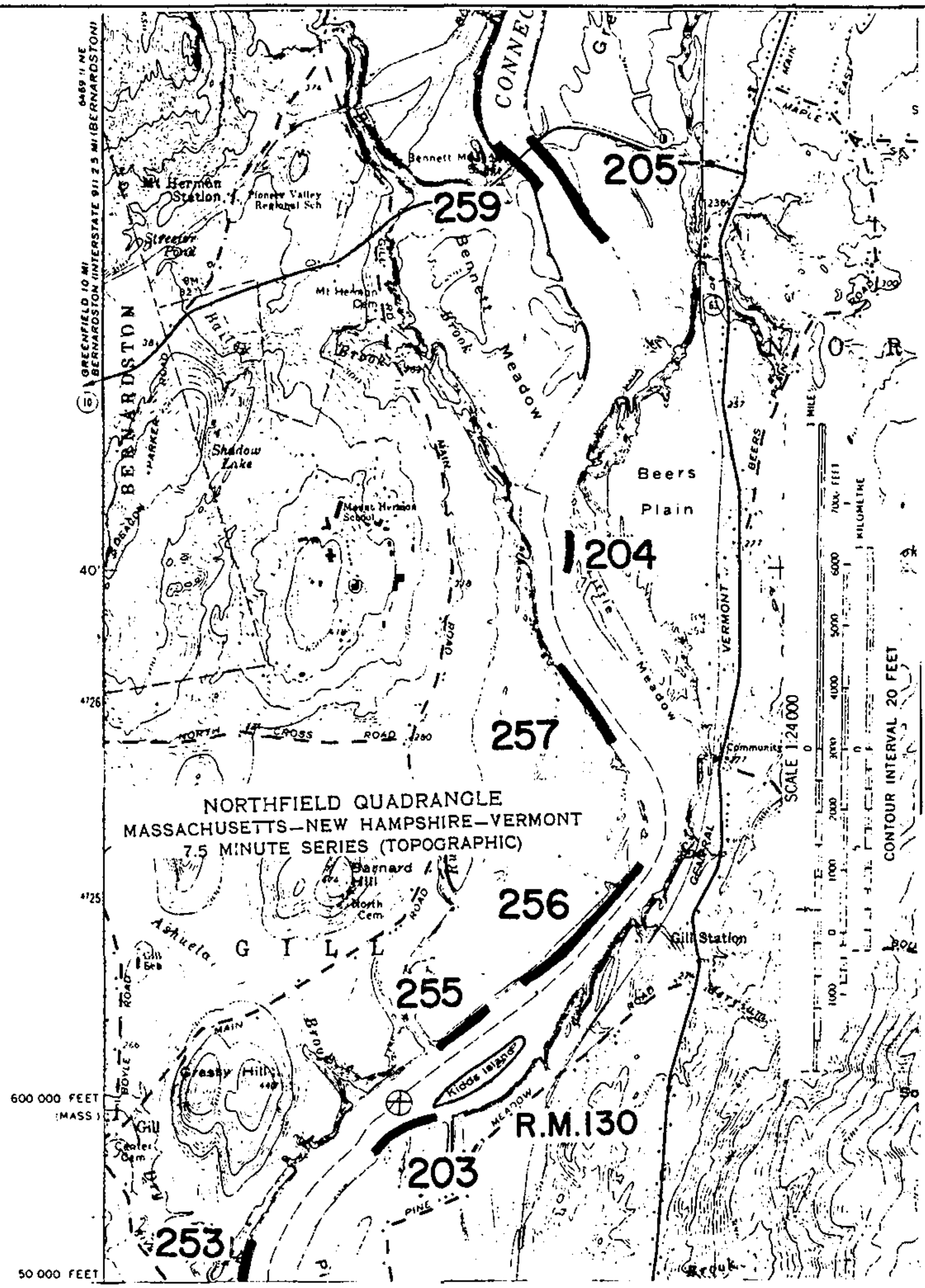


Denotes Eroded Bank, 1979

Connecticut River
Turners Falls to State Line, MA
General Investigation Study

EROSION SITES IDENTIFIED
IN 1979 REPORT

PLATE 15



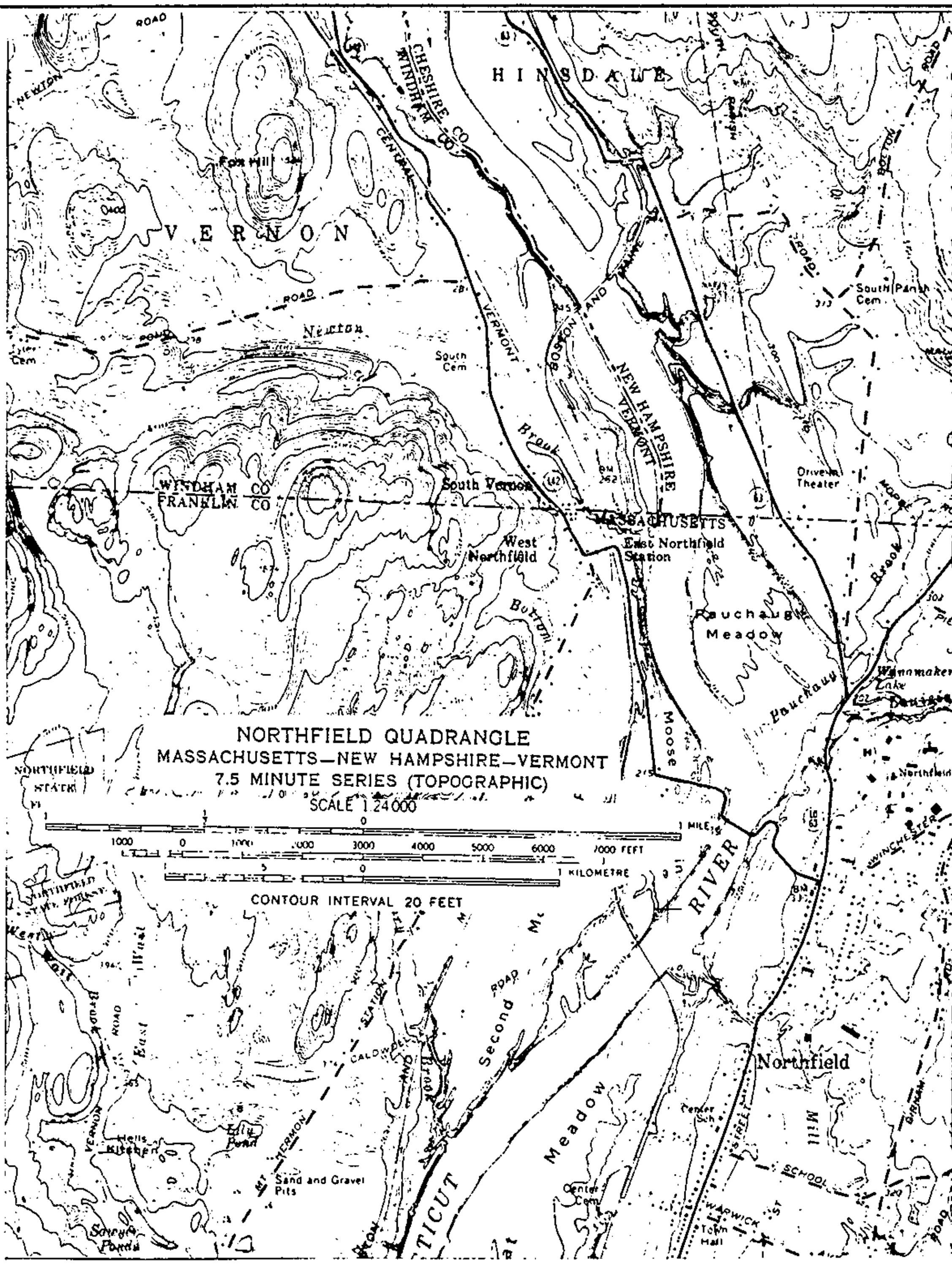
Match Plate 6

Connecticut River
Turners Falls to State Line, MA
General Investigation Study

EROSION SITES IDENTIFIED
IN 1979 REPORT

PLATE 16

▬ Denotes Eroded Bank, 1979



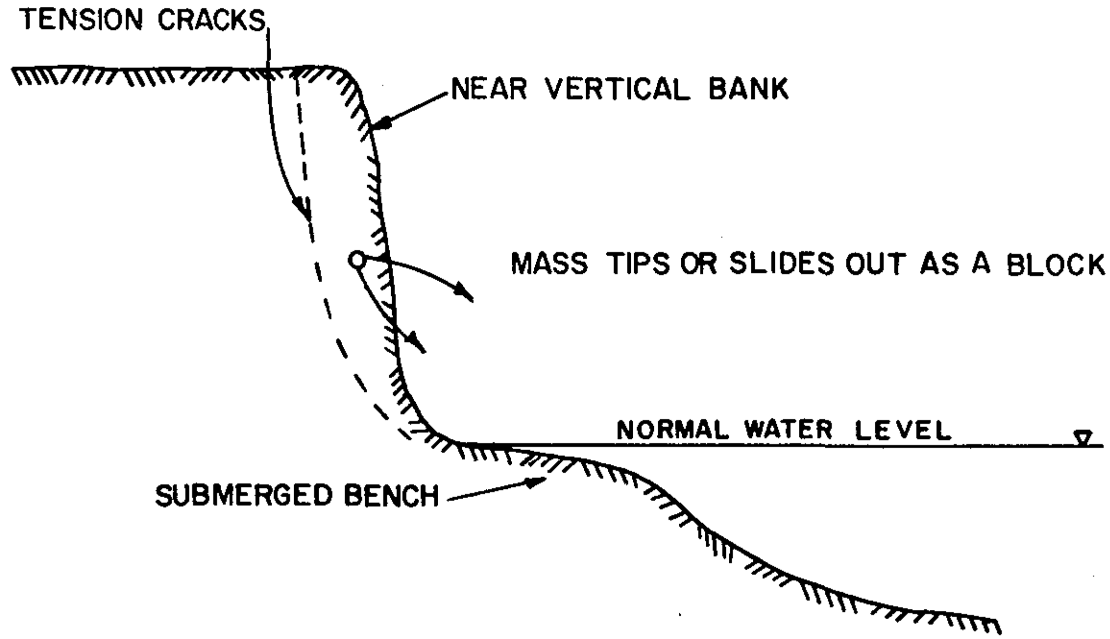
Match Plate 7

Denotes Eroded Bank, 1979

Connecticut River
Turners Falls to State Line, MA
General Investigation Study

EROSION SITES IDENTIFIED
IN 1979 REPORT

PLATE 17



MASS WASTING ON A VEGETATED OR BARREN BANK.

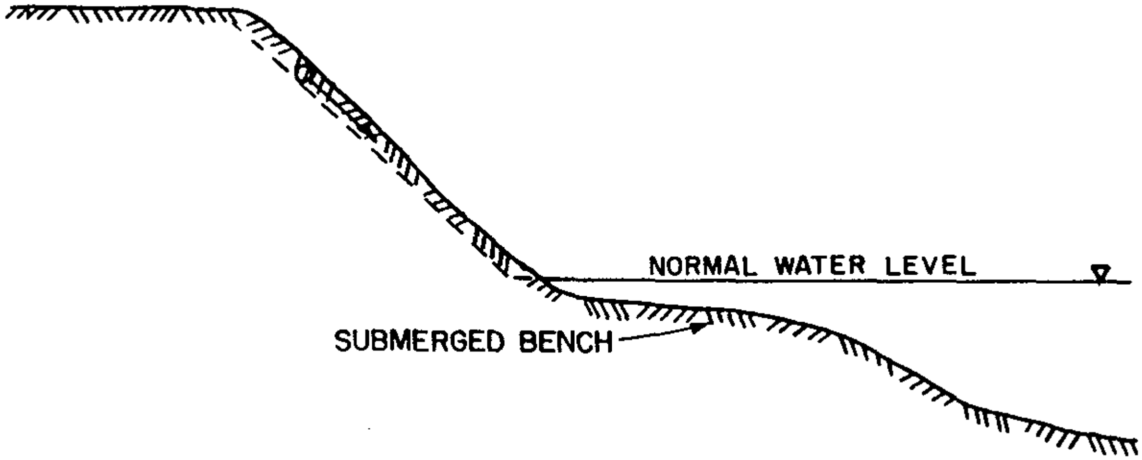
CONNECTICUT RIVER
STREAMBANK EROSION STUDY

**EROSION
SITE CLASSIFICATION**

HYD. & WQ. BR. NOV. 1990

PLATE 18

MATERIAL SLIDES DOWN BANK AS INDIVIDUAL PARTICLES.



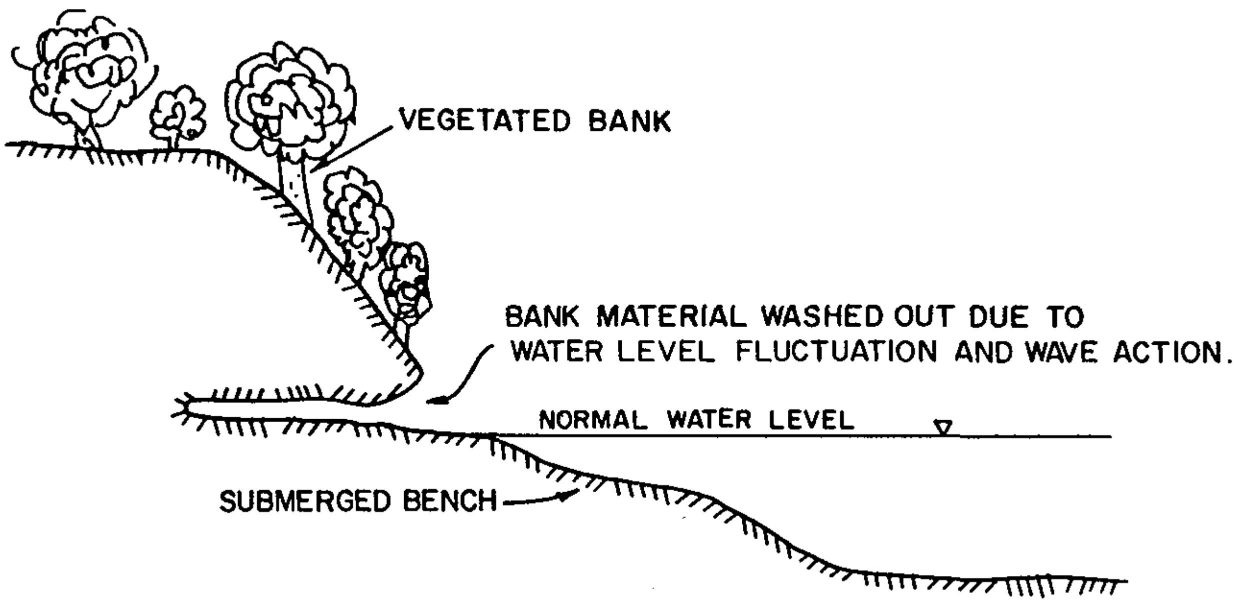
SLOUGHING ON A PARTIALLY VEGETATED OR BARREN BANK.

CONNECTICUT RIVER
STREAMBANK EROSION STUDY

EROSION
SITE CLASSIFICATION

HYD. & WQ. BR. NOV. 1990

PLATE 19



UNDERCUTTING ON A VEGETATED BANK.

CONNECTICUT RIVER
STREAMBANK EROSION STUDY

EROSION
SITE. CLASSIFICATION

HYD. & WQ.BR. NOV. 1990

PLATE 20

Both photographs show erosion conditions on the West Bank of the Connecticut River, opposite Kidds Island, as they existed on April 15, 1977.

Site Number 255 from 1979 report.
Site Number 9 from this report.

Connecticut River
Turners Falls to State Line, MA
General Investigation Study

EROSION SITE PHOTOGRAPHS

PLATE 21

Both photographs show erosion conditions on the West Bank of the Connecticut River, opposite Kidds Island, as they existed on June 20, 1990.

Site Number 9 from this report.
Site Number 255 from 1979 report.

Connecticut River
Turners Falls to State Line, MA
General Investigation Study

EROSION SITE PHOTOGRAPHS

PLATE 22

showed minor scarp development of about 2 to 4 inches, likely from boat waves.

Bank Location. This group was divided into three groups: inside or outside bend, and straight reach. Approximately one-third of the erosion sites were on an outer bend, and about one-half along a straight reach of the river.

Soil Type. Since no location appeared to have a totally cohesive soil, the group was divided into noncohesive and stratified subgroups.

Vegetation. This group was divided into vegetated (having more than 50 percent upper bank vegetation) and barren (less than 50 percent upper bank vegetation).

EROSION FACTORS

General

It is generally accepted by geologists, engineers, and geomorphologists that bank erosion is a natural phenomena common to all alluvial rivers. However, rates of erosion may vary significantly depending on discharge, hydraulic slope, channel geometry, channel configuration, channel slope, bed and bank material, freeze and thaw conditions, pool fluctuation, and wave action. Following is a general summary of erosion factors based on the 1979 Corps report and recent flood analysis.

Hydraulic Factors

There are several hydraulic factors affecting the stability of banks, including specific properties of water, flow rate of the river, and duration of a particular flood discharge. Specific properties of water which affect the hydraulic forces acting on banks of rivers include specific weight, and viscosity of the fluid. Both properties are affected by suspended sediment. The presence of suspended sediment in the flow increases specific weight of the water-sediment mixture and increases its apparent viscosity. These flow characteristics directly affect velocity, velocity distribution, shear stress, and consequently, the channel erosion rate.

In general, with a constant flow rate, a channel achieves an equilibrium over time so that there is little erosion during periods of low flow, there is little erosion, and the channel and bank segments may even experience accretion. During periods of intermediate river flows some bank erosion and deposition occur. With major flood events, major bank erosion occurs. From research evaluated during the 1979 NED report, engineers and scientists generally concluded from field observations that 90 to 99 percent of all significant bank erosion occurred during major flood events. There were two significant flood events within the last 6 years; the first, in May 1984, was one of the top ten record events with a 103,000 cfs flow at Turners Falls Dam (equivalent to an approximate 10- to 15-year event), and, the second, in April 1987 with a flow of 97,400 cfs (equivalent to an approximate 10-year event).

The duration of a particular flow rate is even more important than the magnitude, with the exception of large floods that occur infrequently during periods of intense rainfall, snowmelt, and/ or breakup of ice jams. Nearly constant long term low flow rates tend to stabilize banks due to sediment aggradation and vegetative development which assist in erosion reduction during high flow rates. Long term high or medium flow rates will cause significant continuous sediment removal until channel equilibrium requirements are met. As shown in Plate 7, average flow rates have been higher over the last 20 years than over the period of record at Turners Falls Dam.

Channel Geometry

Geometry of the cross section of a river is an excellent indicator of its erodibility and stability. In the 1979 report, we noted that the Connecticut River was a relatively stable alluvial river due to its relative uniformity, the presence of geologic controls, its bank line vegetation and presence of materials relatively resistant to erosion. It was estimated, however, that approximately 20 percent of the Connecticut River banks (within the reach from Turners Falls Dam to Wells River, Vermont) were experiencing some form of erosion in the 1979 report. This is a significant difference from the 32 percent erosion length estimated in the June 1990 field investigation of Turners Falls pool. This apparent anomaly may be related to the unique hydropower operation within the Turners Falls pool and/or to the significant increase in boating taking place within this stretch of the river. However, at this time without further investigation of the same length analyzed for the 1979 report, it is not known if erosion conditions on the rest of the Connecticut River have also increased proportionately. It was also documented in the 1979 report that geomorphologists' and engineers' rule-of-thumb guidance for rivers of this type indicate that outside banks will move landward annually a distance about equal to the depth of flow. Estimates made from cross sections from flood insurance studies in the area indicate that the water depth for an annual event is typically between 20 to 35 feet. Observed erosion since 1979 generally appears to be somewhat less than these estimates.

Velocity Factors

The velocity is not uniform across the river channel. In long straight reaches the thal weg meanders from side to side and is stronger on one bank than the other. In river bends, the flow impinges strongly on the outside bank. In both cases, the amount of local erosion is dependent on characteristics of the bank material and position, strength, and duration of the velocity along the thalweg.

Tractive Force

The tractive force is the drag force exerted by impingement of flowing water and sediment on the banks. Either tractive force or velocity can be used in the analysis of bank erosion.

Momentum

As water and sediment, ice and other moving objects are stopped or deflected by the riverbank, the mass in motion exerts a force of the bank, stopping or altering its course. The force is equal to the product of the mass of the flowing object multiplied by its change in velocity. Consequently, water and ice can exert significant forces on riverbanks.

Wind Waves

The magnitude and frequency of wind generated waves are dependent on wind velocity and direction, duration of the wind, fetch distance, exposed water surface, and depth of water. Relatively narrow channels with trees on the banks, or located between nearby bluffs or hills such as those in this stretch of the Connecticut River are normally insignificantly affected by bank erosion caused by wind generated waves.

Boat Waves

Surface waves generated by boats can significantly affect bank stability depending on the size, shape, and speed of the boat, frequency of boating, and location or position of speeding boats relative to the channel banks. In the case of the Connecticut River in this stretch, there has been a significant increase in boating activity since construction of the two boat launching sites at Barton's Cove and the state boat ramp near the New Hampshire border. Landowners along the river have noted that increases in boating since the 1979 study have been significant, the results of which were evidenced during the June 1990 field trip by the presence of an almost continuous 2- to 4-inch wave scarp at various levels along barren riverbanks within the Turners Falls pool.

Freezing and Thawing

During winter months, banks of the river are subjected to freezing, subsequent thawing, and ice effects. During the freeze-thaw cycle, portions of unprotected banks may be subjected to frost heaving, causing the soil to become less compacted and resulting in a more easily erodible condition. Also, on an inclined bank, forma tion of ice layers thrust overlaying material outward. During thawing, loosened and displaced material can slump, slide, or fall down the bank.

Subsurface Flow

Water flowing in and out of riverbanks result in bank instability from seepage forces, piping, and mass wasting. Rivers continuously seeping water into the banks tend to have smaller widths and larger depths for a particular discharge. The reverse is true for rivers continuously gaining water by inflow through their banks. This inflowing water creates a seepage force that makes the banks less stable. Fluctuating water levels adjacent to the riverbanks are caused by wind and boat waves, varying stages due to change in river discharges, hydropower pool variations, ice jams, etc. A high water table caused by overland flow or poor local drainage in a nearby flood plain may also cause water to flow toward the riverbanks. In stratified banks, flow is induced in more permeable layers. If flow through the permeable lenses is capable of dislodging and transporting particles, portions of the bank are undermined and a block of material may drop down. This results in development of tension cracks that may allow surface flows to enter, further reducing stability of the affected block of bank material. Bank erosion may continue on a grain-by-grain basis or the block of bank material may ultimately slide downward and outward into the channel causing bank failure as a result of seepage forces, piping, and mass wasting.

EVALUATION OF CAUSES WITHIN THE STUDY REACH

Analytical Evaluation of Forces

In the 1979 report, major causes of bank erosion for the 141-mile long portion of the Connecticut River from Turners Falls Dam to the headwaters of the Wilder Dam hydropower pool were first identified and subsequently evaluated, using available data, current theory, personal experience and sound professional judgement. The tasks included developing the relative importance of factors causing erosion and relative magnitude of bank erosion problems for different river conditions. A summation of the relative magnitude of bank erosion for different factors causing erosion is given in Table 16. This table indicates the relative importance of these factors for the entire reach. Factors listed in decreasing importance are: shear stress (velocity or tractive force), pool fluctuation, boat waves, gravitational forces, seepage forces, stage variation, wind waves, ice, flood variation, and freeze-thaw. Tractive shear stress exerted on the channel banks by high velocity flow is the major force causing bank erosion, particularly during major floods. The magnitude of this shear velocity depends upon geometry of the channel, configuration of the channel, i.e., whether the flow is in a straight reach, or along the outside of a bend or in some other location.

As noted, the next most significant cause of erosion is pool fluctuations which can cause an increase in instability on the order of 18 percent of the shear stress exerted on the bank by flowing water. The impacts of hydropower developmenton bank stability in Turners Falls Pool have been and continue to be more severe than for other hydropower pools studied in the 1979 report due to differences in operation. The increase in pool level, the larger pool fluctuations and flow reversals caused by the present hydropower operation all contribute to the documented bank instabilities. It was noted that pool fluctuations, on the order of 5 feet, as experienced in the Turners Falls pool, are at least twice as destructive to banks as 1 to 3 foot fluctuations in other hydropower pools studied.

Other causes of upper bank erosion, such as wind-generated waves, boat generated waves, ice, etc. have a lesser impact on long term bank stability, but nevertheless can cause significant erosion rates near the water surface-bank interface.

Further analysis was also completed in the 1979 report for different site conditions in the 141 mile long study reach and the results are presented in Table 17. This table demonstrates that a reach with a high bank is more susceptible to erosion; vegetation is important in stabilizing high banks; and the natural river has higher potential for bank erosion than pools. From this analysis, it was considered that the natural river is roughly one-third more susceptible to major bank erosion than pools.

Table 18 summarizes statistics of erosion sites within Turners Falls pool as taken from the 1979 report. This table indicates that the predominant bank height of the observed erosion sites was low (less than 15 feet). The most common type of erosion is the "sloughing" variety. In addition we found that most observed erosion sites are located in straight reaches, noncohesive soil and vegetated areas. The 1990 classification yields similar conclusions as shown on Table 15; however, a much larger percentage of barren riverbank appears in the present study.

TABLE 16

SUM OF RELATIVE MAGNITUDE
OF FACTORS CAUSING EROSION

Variables Causing Erosion	Noncohesive	Stratified
Shear stress or velocity	359* (1.0)**	315 (0.88)
Flood variation	10 (0.03)	10 (0.03)
Stage variation	27 (0.08)	24 (0.07)
Pool fluctuation	63 (0.18)	54 (0.17)
Wind waves, surface erosion and piping	14 (0.04)	14 (0.04)
Boat waves, surface erosion and piping	34 (0.09)	42 (0.13)
Freeze-thaw	6 (0.02)	6 (0.02)
Ice	11 (0.03)	10 (0.03)
Seepage forces	28 (0.08)	38 (0.12)
Gravitational forces	31 (0.09)	40 (0.13)

* The higher the number, the greater the impact of the individual erosion variable. These numbers are totals obtained by summing assigned values of basic erosion variables extracted from the 1979 COE report.

** Each number was compared with the number assigned to shear stress or velocity "359" to come up with a standardized value which is shown in parentheses (i.e. for pool fluctuations 63 divided by 359 equals 0.18). Basically, the table should be used to show order of magnitude only since this is an approximation at best.

TABLE 17

SUM OF RELATIVE MAGNITUDE
OF BANK EROSION POTENTIAL

Conditions	Noncohesive	Stratified	Average
Natural river	112* (1.00)**	107 (0.96)	109.5 (0.98)
Natural river with high banks	124 (1.11)	112 (1.00)	118.0 (1.05)
Pools: low banks	103 (0.92)	97 (0.87)	100.0 (0.89)
Pools: low banks with vegetation	69 (0.62)	66 (0.59)	67.5 (0.60)
Pools: high banks	106 (0.95)	102 (0.91)	104.0 (0.95)
Pools: high banks with vegetation	69 (0.62)	69 (0.62)	60.0 (0.62)

* The numbers are used to compare to natural river conditions. The greater the number, the greater the chance of erosion potential. These numbers are totals obtained from summing assigned values of erosion-causing factors for each river condition as extracted from the 1979 COE report. Refer to the 1979 report for more information.

** Standardized values based on the natural river with noncohesive banks. For example, for pools with low and noncohesive banks, 100/112 = 0.89.

TABLE 18

STATISTICS OF EROSION SITES ACCORDING TO CLASSIFICATION

Area	Stat's	Bank Height		Erosion Type					Erosion Site Location				Bank Location			Soil Type			Vegetation		Total
		Low <15'	High ≥15'	Mass Wast'g	Head Cut'g	Sloughing	Shoal'g Wash'g	Under-cut'g	Upper Pool	Mid Pool	Low Pool	Nat' Reach	Outer Bend	Inner Bend	Straight Reach	Coh's	Non Coh's	Strat'	Vegt'd	Barren	
Turners Falls Pool	#	9	4	2	2	7	2	0	2	9	2	0	3	2	8	0	7	6	9	4	13
	%	69	31	15	15	55	15	0	15	69	16	0	23	15	62	0	54	46	69	31	

Source: 1979 Corps study.

Causes of bank erosion are not only a function of forces but also related to erodibility of banks. Changes in water surface elevation due to impoundment can reduce some forces such as shear stress but at the same time expose more erodible material to flow and reduce vegetative growth; hence, increasing bank erosion.

Progression of Erosion

The progression of erosion along a particular riverine cross section can be attributed to the location where forces act on the riverbank. These forces can be broken into two categories: (1) those that act at and near the surface of the water associated with pool fluctuations, related piping, groundwater, wind waves, boat waves, ice, lack of or removal of vegetation, and (2) forces acting on the full height of the submerged bank, the major component of which is the velocity or tractive force. From a literature search, it was noted that the tractive force does not act equally along the full face of the bank. Maximum tractive shear stress acts upon the banks of the channel approximately two-thirds of the depth below the air-water interface. Therefore, to protect against shear force, any revetment scheme must extend significantly below the normal water line.

The action of forces near the flow surface causes some erosion on banks and may induce piping in lenses of noncohesive material in the upper part of the submerged bank. If these were the only forces to which the bank line was subjected, the bank would gradually adjust by developing a shelf or platform area wide enough to dissipate the forces causing erosion, increasing upper bank stability as the adjustment occurred. It was estimated in the 1979 report that the extent of this erosion landward would in most cases be limited to an average of 10 to 15 feet even in a large river.

The next phase of bank erosion to take place is that caused by high velocity flows. The bank subjected to surface forces would now be subjected to forces acting with a maximum magnitude at a distance of about two-thirds depth of water below the surface. With an occurrence of a major flood event, erosion of the total bank occurs and the major bank line moves landward. As the bank line moves landward, the berm formed by water surface fluctuations and related phenomena is overtaken and in many cases the bank line moves so far landward that effects of the near-surface erosion are wiped out. After termination of the flood event, surface forces can go to work on the bank line again to form a new berm. As a way of illustration, we note that during both the 1978 and 1990 field visits that there was limited development of beaches near the water surface, indicating that surface related erosion is often erased by erosion of the total bank by velocity related forces, such as large flood events.

In the 1979 report, it was also emphasized that upper bank stabilization or protection will usually fail during major flood events if lower bank protection is not provided. If toe protection is provided and no upper bank protection included, there may be some erosion in the upper bank area; however, after a berm has formed and the upper bank stabilized, further erosion will be minor.

CONCLUSIONS

The information gained in this study indicates that riverbank erosion has significantly increased over that documented in the 1979 report. Total shoreline length currently undergoing some form of active erosion, based on the June 1990 field visit is approximately 47,000 linear feet or approximately one-third of the 148,000 linear feet of shoreline located in the Massachusetts portion of Turners Falls pool. This is an approximate threefold increase over that estimated as part of the 1979 report (the estimated shoreline length undergoing some form of active erosion during September 1978 was 17,000 linear feet).

The Connecticut River Basin continues to be a highly regulated watershed with numerous non-Federal water resource developments for hydropower, recreation, water supply, and conservation. The system of Corps of Engineers flood control reservoirs has a major impact in reducing discharge and erosive potential accompanying severe floods in the basin. Since completion of the Turners/Northfield pumped storage system, the Turners Falls pool has remained the most dynamic of all power pools on the Connecticut River with daily fluctuations averaging about 3.5 feet and with extremes observed in the order of 5 feet. Hydrologically, the last 20 years have seen higher than normal day-to-day riverflow at the Turners Falls gage as well as two recent major floods, May 1984 and April 1987. Recreational boating activity has markedly increased with construction of public river access points. These factors, coupled with the natural environment, have shaped the present state of erosion in Turners Falls pool.