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DESIRABLE LOW FLOW RELEASES FROM IMPOUNDING RESERVOIRS: FISH HABITATS AND RESERVOIR COSTS

Volume I

by

Krishan P. Singh, Ph.D., Principal Scientist
Ganapathi S. Ramamurthy, Graduate Research Assistant

Prepared for
Illinois Environmental Protection Agency

Champaign, Illinois
September 1981

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INTRODUCTION

Modification of river flow resulting from the construction and operation of a dam or impounding structure has been identified as a significant factor causing water quality and aquatic habitat problems. State, local, and corporate water use planning often presumes that all water in a stream is potentially available for off-stream uses. This assumption clearly contradicts legislative mandates regarding the public interest in preserving water in the stream for instream flow uses, e.g., for water quality and aquatic organisms, fish and wildlife.

The U.S. Fish and Wildlife Service (FWS) has been trying to identify promising strategies for reserving instream flows (Dewsnup et al., 1977; Gould et al., 1977). Some of the strategies that may be considered are:

1) Imposing conditions and restrictions, designed to protect and preserve instream flow needs, on applications to appropriate (for example, the approval of a reservoir might be conditioned on the release of water during certain periods of the year to sustain the downstream fishery). The use of this strategy requires a state policy that affords some measure of protection to instream values.
2) Appropriating water for instream flow needs by authorizing a state agency to appropriate water to maintain minimum streamflows and protect the natural stream environment.
3) Planning programs for the statewide water plans to identify and indicate the amount of streamflows to be reserved for instream uses at various times of the year.

It should be noted that Public Law 92-500 makes provision for minimum flows when projects are constructed or licensed by federal agencies. The administrator of the Environmental Protection Agency is authorized to specify minimum flows required for maintaining streamwater quality, and other federal agencies are authorized to determine the minimum flows required to support fish and wildlife.

Low flow criteria for fish and wildlife need to be developed for determining the suitability of various low flow regimens for fish and wildlife. In order to choose a minimum low flow release which keeps the fishery in good condition and, at the same time, does not unduly saddle the developer with extra cost, the decision maker needs to know the estimated increase in cost of a reservoir to provide minimum low flow over that with no such flow, for a range of low flows. The extra cost of impoundment may not be considered by the developer as a gift to the fishery and water quality interests; rather, it may be considered a fee that he pays for the use of water resources (presently enjoyed by the downstream interests) and for altering the streamflow regimen to meet his particular needs.

A study on water quality control through flow augmentation from upland reservoirs (EPA, 1971) was undertaken in a 60-mile section of the Sandusky River in North Central Ohio. The main findings of this study are: 1) chemicals such as calcium, magnesium, fluoride, and sodium had lower concentrations at high flows and vice versa, 2) concentrations of total phosphorus and soluble orthophosphorus were lower during low flow periods than high flow periods (probably due to agricultural surface runoff), 3) immediately downstream from sewage treatment plants, orthophosphorus concentrations did increase with decreasing river flow, 4) nitrate and potassium concentrations were variable and showed no correlation with river flow, and

5) oxygen concentrations varied widely above and below saturation at low flows. Some such studies are needed for Illinois streams to assess the effect of low flows on various water quality parameters.

In order to develop information on fish suitability or preference for different flow releases and the associated incremental costs, the investigations and analyses presented in this report are arranged under the following heads:

Hydraulic Geometry Parameters. Daily flow data at 123 gaging stations were analyzed to evaluate low flows at 8 levels. Relations between mean velocity and flow and between mean depth and flow were established for the low flow range at each of the 123 stations selected. A brief review of the information on riffles and pools provided a measure of estimating mean depth in pools when the mean depth at the riffle is known.

Evaporation and Sedimentation. Information on net lake evaporation (i.e., lake evaporation minus precipitation) for different drought durations and recurrence intervals was available from Illinois State Water Survey Bulletin 51A (Terstriep et al., in preparation, 1981). The sediment data on 98 lakes, surveyed over the years by State Water Survey personnel, were used in developing regional relations between percent capacity loss and reservoir capacity-inflow ratio.

Fish Suitability Curves. Data on fish suitability or preference versus flow velocity and flow depth for both juveniles and adults of the nine target fish (bluegill, bluntnose, carp, channel cat, largemouth bass, smallmouth bass, drum, white bass, and white crappie) was furnished by the Illinois Environmental Protection Agency. The domains of suitability in terms of velocity and depth of flow were analyzed for each fish species.

Methodology and Computer Program. Computer programs were developed to generate information on fish suitability for each of the eight low flow releases at each of the 123 stations, and to compute the capital cost of reservoirs with storage adequate to meet four supply rates, eight low flow releases, and various design droughts. The extra capital cost equals cost with a low flow release minus the cost with no mandatory release at a given set of net supply, design drought, and low flow release parameters.

Analyses and Results. The fish suitability and capital cost data are developed for all the study stations. However, five river basins (each with three stations with increasing drainage area) are analyzed in detail to assess the suitable levels of low flow releases and the associated incremental capital costs.

Conclusions and Suggestions. The main findings are highlighted and suggestions are made to improve the methodology for evaluating fish preferences. The necessary field work, data collection, research, and technology are described briefly.

Acknowledgments

The study was jointly supported by the Illinois Environmental Protection Agency and the Illinois State Water Survey of the Illinois Department of Energy and Natural Resources (previously, Illinois Institute of Natural Resources). William Rice of the Illinois Environmental Protection Agency served in a liaison capacity during the course of this study. Masahiro Nakashima, graduate research assistant, helped in finalization of the report. Linda Riggin prepared the illustrations and Kathy Brown typed the final report.

HYDRAULIC GEOMETRY PARAMETERS

The following criteria were used in selecting the stations for determining the hydraulic geometry parameters at various low flow releases:

1) The daily flow record should be 16 years or more to provide satisfactory flow estimates for low flow release criteria.
2) The flow corresponding to 90 percent duration should be greater than zero.
3) The Wabash, Ohio, and Mississippi Rivers (i.e., the interstate rivers) are not to be included.

A total of 127 gaging stations met the above criteria. However, four stations were excluded (04091500 - Little Calumet River at Harvey, 05538000- Des Plaines River at Joliet, 05560000 - Illinois River at Peoria, and 05584000 - Illinois River at Beardstown) because the daily flow data available are for the years prior to 1939 and because the flows in later years have significantly changed from the previous flows because of changes in regulation procedures.

The final list of 123 selected gaging stations is given in table 1, which contains the USGS number, stream and gaging station, drainage area in square miles, mean flow in cfs obtained from the USGS publications on Water Resources Data in Illinois, and the 7-day 10-year low flow for the 1970 effluent level (Singh and Stall, 1973). The locations of these gaging stations are shown in figure 1.

Low Flow Release Criteria

The U.S. Geological Survey publishes observed daily flows at various gaging stations on streams in Illinois every year. These daily flow data, updated to September 1976, are available on DISK at the State Water Survey for quick

TABLE 1. STREAM GAGING STATIONS IN ILLINOIS

NO.	USGS NO.	STREAM AND GAGING STATION	D.A. IN SQ MI	Q(7,10) CFS	MEAN Q CFS
1	03336900	SALT FORK NEAR ST. JOSEPH	134	3.60	110
2	03337000	BONEYARD CREEK AT URBANA	4.46	0.70	4.51
3	03337500	WEST BRANCH SALT FORK AT URBANA	68	1.00	51.5
4	03338500	VERMILION RIVER NEAR CATLIN	958	19.0	704
5	03339000	VERMILION RIVER NEAR DANVILLE	1290	33 .0	939
6	03343400	EMBARRAS RIVER NEAR CAMARGO	186	0.00	154
7	03345500	EMBARRAS RIVER AT STE. MARIE	1516	16.6	1216
8	03346000	NORTH FORK EMBARRAS RIVER NEAR OBLONG	319	0.00	252
9	03379500	LITTLE WABASH RIVER BELOW CLAY CITY	1131	0.47	881
10	03380500	SKILLET FORK AT WAYNE CITY	464	0.00	392
11	03381500	LITTLE WABASH RIVER AT CARMI	3102	5.70	2521
12	03612000	CACHE RIVER AT FORMAN	244	0.00	299
13	05415500	E. F. GALENA RIVER AT COUNCIL HILL	17.6	2.30	12.3
14	05419000	APPLE RIVER NEAR HANOVER	247	20.1	167
15	05420000	PLUM RIVER BELOW CARROLL CK. NEAR SAVANNA	230	10.7	147
16	05435500	PECATONICA RIVER AT FREEPORT	1326	181.0	890
17	05437000	PECATONICA RIVER AT SHIRLAND	2550	393	1513
18	05437500	ROCK RIVER AT ROCKTON	6363	795	3892
19	05438250	COON CREEK AT RILEY	85.1	2.60	63.8
20	05438500	KISHWAUKEE RIVER AT BELVIDERE	538	34.3	337
21	05439500	S. B. KISHAWAUKEE RIVER NEAR FAIRDALE	387	9.90	253
22	05440000	KISHWAUKEE RIVER NEAR PERRYVILLE	1099	62.3	690
23	05440500	KILLBUCK CREEK NEAR MONROE CENTER	117	3.10	59.7
24	05441000	LEAF RIVER AT LEAF RIVER	103	8.40	55.7
25	05443500	ROCK RIVER AT COMO	8755	1097	5071
26	05444000	ELKHORN CREEK NEAR PENROSE	146	15.5	95.1
27	05445500	ROCK CREEK NEAR MORRISON	158	13.6	92.2
28	05446500	ROCK RIVER NEAR JOSLIN	9551	1306	5870
29	05447000	GREEN RIVER AT AMBOY	201	4.90	93.0
30	05447500	GREEN RIVER NEAR GENESEO	1003	49.2	595
31	05448000	MILL CREEK AT MILAN	62.4	0.10	42.0
32	05466000	EDWARDS RIVER NEAR ORION	155	1.70	103
33	05466500	EDWARDS RIVER NEAR NEW BOSTON	445	6.80	273
34	05467000	POPE CREEK NEAR KEITHSBURG	183	1.90	103
35	05467500	HENDERSON CREEK NEAR LITTLE YORK	151	0.03	88.8
36	05468500	CEDAR CREEK AT LITTLE YORK	130	7.40	87.3
37	05469000	HENDERSON CREEK NEAR OQUAWKA	432	7.80	279
38	05495500	BEAR CREEK NEAR MARCELLINE	349	0.00	199
39	05510500	HADLEY CREEK AT KINDERHOOK	72.7	0.00	53.5
40	05512500	BAY CREEK AT PITTSFIELD	39.4	0.00	26.7

TABLE 1. CONTINUED

NO.	USGS NO.	STREAM AND GAGING STATION	D.A. IN SQ MI	Q(7,10) CFS	MEAN Q CFS
41	05513000	BAY CREEK AT NEBO	161	0.00	96.7
42	05520000	SINGLETON DITCH AT ILLINOI	220	12.7	182
43	05520500	KANKAKEE RIVER AT MOMENCE	2294	411	1928
44	05525000	IROQUOIS RIVER AT IROQUOIS	686	9.10	536
45	05525500	SUGAR CREEK AT MILFORD	446	3.50	351
46	05526000	IROQUOIS RIVER NEAR CHEBANSE	2091	16.6	1607
47	05526500	TERRY CREEK NEAR CUSTER PARK	12.1	0.03	9.46
48	05527000	KANKAKEE RIVER AT CUSTER PARK	4810	445	3540
49	05527500	KANKAKEE RIVER NEAR WILMINGTON	5150	451	4092
50	05529000	DES PLAINES RIVER NEAR DES PLAINES	360	4.30	246
51	05531000	SALT CREEK NEAR ARLINGTON HEIGHTS	32.1	0.00	23.3
52	05531500	SALT CREEK AT WESTERN SPRINGS	114	14.9	104
53	05532000	ADDISON CREEK AT BELLWOOD	17.9	1.80	13.9
54	05532500	DES PLAINES RIVER AT RIVERSIDE	630	18.4	448
55	05533000	FLAG CREEK NEAR WILLOW SPRINGS	16.5	2.50	16.2
56	05533500	DES PLAINES RIVER AT LEMONT	684	24.8	434
57	05535000	SKOKIE RIVER AT LAKE FOREST	13.0	1.30	11.9
58	05535500	W. F. OF N. B. CHICAGO RIVER AT NORTHBROOK	11.5	1.40	12.1
59	05536000	NORTH BRANCH CHICAGO RIVER AT NILES	100	7.60	88.3
60	05536215	THORN CREEK AT GLENWOOD	24.7	14.0	36.5
61	05536235	DEER CREEK NEAR CHICAGO HEIGHTS	23.1	3.00	17.2
62	05536255	BUTTERFIELD CREEK AT FLOSSMOOR	23.5	1.00	17.4
63	05536265	LANSING DITCH NEAR LANSING	8.84	0.00	7.83
64	05536270	NORTH CREEK NEAR LANSING	16.8	0.05	14.6
65	05536275	THORN CREEK AT THORNTON	104	21.3	98.5
66	05536290	LITTLE CALUMET RIVER AT SOUTH HOLLAND	205	34.0	178
67	05536340	MIDLOTHIAN CREEK AT OAK FOREST	12.6	0.00	10.9
68	05539000	HICKORY CREEK AT JOLIET	107	1.90	83.0
69	05539900	W. B. DU PAGE RIVER NEAR WEST CHICAGO	28.5	3.20	30.1
70	05540500	DU PAGE RIVER AT SHOREWOOD	324	45.0	249
71	05542000	MAZON RIVER NEAR COAL CITY	455	0.00	320
72	05543500	ILLINOIS RIVER AT MARSEILLES	8259	3240	10700
73	05549000	BOONE CREEK NEAR MCHENRY	15.5	3.70	13.1
74	05550000	FOX RIVER AT ALGONQUIN	1403	51.0	821
75	05550500	POPLAR CREEK AT ELGIN	35.2	0.96	23.7
76	05551200	FERSON CREEK NEAR ST. CHARLES	51.7	0.23	38.9
77	05551700	BLACKBERRY CREEK NEAR YORKVILLE	70.2	2.50	50.2
78	05552500	FOX RIVER AT DAYTON	2642	198	1657
79	05554000	N. F. VERMILION RIVER NEAR CHARLOTTE	186	0.00	124
80	05554500	VERMILION RIVER AT PONTIAC	579	0.20	378

TABLE 1. CONCLUDED

NO.	USGS NO.	STREAM AND GAGING STATION	D.A. IN SQ MI	Q(7,10) CFS	MEAN Q CFS
81	05555500	VERMILION RIVER AT LOWELL	1278	7.30	734
82	05556500	BUREAU CREEK AT PRINCETON	196	0.92	131
83	05558500	CROW CREEK (WEST) NEAR HENRY	56.2	0.00	36.0
84	05560500	FARM CREEK AT FARMDALE	27.4	0.00	18.2
85	05562000	FARM CREEK AT EAST PEORIA	61.2	0.00	43.8
86	05563000	KICKAPOO CREEK NEAR KICKAPOO	119	0.53	66.7
87	05563500	KICKAPOO CREEK AT PEORIA	297	1.00	168
88	05567500	MACKINAW RIVER NEAR CONGERVILLE	767	0.54	487
89	05568000	MACKINAW RIVER NEAR GREEN VALLEY	1089	25.5	688
90	05568500	ILLINOIS RIVER AT KINGSTON MINES	15819	3000	14632
91	05568800	INDIAN CREEK NEAR WYOMING	62.7	0.12	45.5
92	05569500	SPOON RIVER AT LONDON MILLS	1062	9.80	693
93	05570000	SPOON RIVER AT SEVILLE	1636	19.0	1030
94	05571000	SANGAMON RIVER AT MAHOMET	362	0.29	261
95	05572000	SANGAMON RIVER AT MONTICELLO	550	2.10	400
96	05574500	FLAT BRANCH NEAR TAYLORVILLE	276	0.00	203
97	05575500	SOUTH FORK SANGAMON RIVER AT KINCAID	562	0.79	408
98	05576000	SOUTH FORK SANGAMON RIVER NEAR ROCHESTER	867	0.84	571
99	05576500	SANGAMON RIVER AT RIVERTON	2618	37.2	1695
100	05578500	SALT CREEK NEAR ROWELL	335	2.20	237
101	05579500	LAKE FORK NEAR CORNLAND	214	2.00	146
102	05580000	KICKAPOO CREEK AT WAYNESVILLE	227	0.48	152
103	05580500	KICKAPOO CREEK NEAR LINCOLN	306	2.50	187
104	05581500	SUGAR CREEK NEAR HARTSBURG	333	11.9	197
105	05582000	SALT CREEK NEAR GREENVIEW	1804	68.6	1235
106	05582500	CRANE CREEK NEAR EASTON	26.5	0.89	16.3
107	05583000	SANGAMON RIVER NEAR OAKFORD	5093	206	3261
108	05584500	LA MOINE RIVER AT COLMAR	655	0.78	432
109	05585000	LA MOINE RIVER AT RIPLEY	1293	9.00	780
110	05585500	ILLINOIS RIVER AT MEREDOSIA	26028	3500	21379
111	05587000	MACOUPIN CREEK NEAR KANE	868	2.00	532
112	05589500	CANTEEN CREEK AT CASEYVILLE	22.6	0.06	17.1
113	05590000	KASKASKIA RIVER AT BONDVILLE	12.4	0.05	10.1
114	05592000	KASKASKIA RIVER AT SHELBYVILLE	1054	10.0	738
115	05592500	KASKASKIA RIVER AT VANDALIA	1940	25.7	1412
116	05593000	KASKASKIA RIVER AT CARLYLE	2719	50.0	1944
117	05594000	SHOAL CREEK NEAR BREESE	735	0.20	515
118	05595000	KASKASKIA RIVER AT NEW ATHENS	5181	93.0	3622
119	05596000	BIG MUDDY RIVER NEAR BENTON	502	30.6	452
120	05597000	BIG MUDDY RIVER AT PLUMFIELD	794	31.0	699
121	05599000	BEAUCOUP CREEK NEAR MATTHEWS	292	0.00	223
122	05599500	BIG MUDDY RIVER AT MURPHYSBORO	2162	35.2	1788
123	05600000	BIG CREEK NEAR WETAUG	32.2	0.00	36.4

Figure 1. Locations of 123 study gaging stations

computer processing. The following eight low flow release levels were considered in evaluation of economic and other impacts for mandating a particular low flow release from an impounding reservoir.

1) Median 31-day low flow during the period May-October, Q(31)P
2) Half median 31-day low flow during the period May-October, 0.5Q(31)P
3) Median 61-day low flow during the period May-October, Q(61)P
4) Half median 61-day low flow during the period May-October, 0.5Q(61)P
5) Flow at 90 percent duration using daily flows May-October, Q(90)P
6) Flow at 85 percent duration using daily flows May-October, Q(85)P
7) Flow at 90 percent duration using daily flows for the record, Q(90)
8) Flow at 85 percent duration using daily flows for the record, Q(85)

The partial record, May through October, was used to determine whether Q(90) and Q(85) were higher or lower than Q(90)P and Q(85)P, respectively.

In developing the flow-duration information, two probability levels were determined for a flow Q: p_1 for flow $\leq$ Q and p_2 for $\geq$ Q. Then, the flow-duration, p, in percent for flow Q is:

$$p = [p_2 + (100 - p_1)]/2$$

Let there be 21 daily flows equal to Q cfs in the daily flow record at a gaging station. Assuming the normal law of errors, the developed flow-duration applies to 11th Q value, and allows 10 values to be slightly lower (but not lower than the next lower observed value) and 10 values to be slightly higher (but not higher than the next higher observed value). A few examples are given on the next page.

USGS No. 03 345500

P_1	P_2	P	Q,cfs
0.10	99.94	99.92	3.00
0.30	99.89	99.80	4.00
0.50	99.54	99.52	9.00
1.12	99.05	98.96	13.00
2.10	98.23	98.07	17.00
3.05	97.33	97.14	20.00
5.20	95.13	94.97	26.00
10.36	90.04	89.84	40.00
15.11	85.06	84.97	57.00
20.15	80.14	79.99	82.00

USGS No. 03 346000

P_1	P_2	P	Q,cfs
1.13	100.00	99.43	0.00
2.33	98.36	98.02	0.20
3.16	97.26	97.05	0.40
5.14	95.21	95.03	1.00
10.14	90.15	90.01	2.40
15.23	85.09	84.93	4.40
20.17	80.01	79.92	6.60

The flow at 85 and 90 percent duration were determined by straight-line interpolation.

The lowest average flows over 31-day and 61-day periods during May through October each year as well as the mid-date of the low flow occurrence were calculated for each year of record at a gaging station. These flows were ranked from low to high and the flow at the 50 percent probability or a 2-year recurrence interval was interpolated from the flows at the nearest lower and higher probability levels.

Computer programs were developed for calculating the 8 flow releases at each of the 123 gaging stations. The flow releases are listed in table 2 for levels 1, 2, 3, 4, 5, 6, 7, and 8. Low flow releases for levels 2 and 4 are 50 percent of those for levels 1 and 3.

Concept of Hydraulic Geometry

The concept of hydraulic geometry of a stream system was first stated by Leopold and Maddock (1953). It suggested relationships between width, W, flow depth, D, and flow velocity, V, at a particular cross section of the stream, and the discharge, Q. The relationships are expressed by:

$$W = a\ Q^b$$

$$D = c\ Q^f$$

$$V = k\ Q^m$$

TABLE 2. Q, V, and D for 8 low-flow release conditions

	Values for Q, V, & D for conditions*							
ITEM	C1	C2	C3	C4	C5	C6	C7	C8
1.	03336900	Salt Fork near St. Joseph						
Q	10.20	5.10	13.10	6.55	9.20	10.00	9.50	11.00
V	0.55	0.39	0.62	0.44	0.52	0.54	0.53	0.57
D	0.52	0.47	0.54	0.49	0.51	0.52	0.52	0.53
2.	03337000	Boneyard Creek at Urbana						
Q	1.97	0.99	2.61	1.31	1.23	1.38	1.20	1.32
V	0.41	0.25	0.50	0.30	0.29	0.32	0.29	0.31
D	0.48	0.44	0.50	0.46	0.45	0.46	0.45	0.46
3.	03337500	West Branch Salt Fork at Urbana						
Q	4.83	2.42	6.22	3.11	3.65	4.32	4.00	4.68
V	0.31	0.22	0.35	0.25	0.27	0.29	0.28	0.30
D	0.51	0.39	0.56	0.43	0.45	0.49	0.47	0.50
4.	03338500	Vermilion River near Catlin						
Q	36.50	18.30	40.00	20.00	27.45	32.49	31.33	36.84
V	0.43	0.33	0.45	0.34	0.38	0.41	0.40	0.43
D	1.04	0.93	1.06	0.94	0.99	1.02	1.02	1.05
5.	03339000	Vermilion River near Danville						
Q	61.50	30.80	74.80	37.40	42.36	54.22	50.48	65.52
V	0.28	0.16	0.33	0.19	0.21	0.26	0.24	0.30
D	1.66	1.45	1.73	1.51	1.55	1.62	1.60	1.68
6.	03343400	Embarras River near Camargo						
Q	2.08	1.04	6.45	3.23	0.69	1.75	1.38	3.25
V	0.48	0.46	0.52	0.50	0.45	0.48	0.47	0.50
D	0.32	0.21	0.61	0.41	0.17	0.29	0.25	0.41
7.	03345500	Embarras River at Ste. Marie						
Q	54.30	27.20	83.80	41.90	38.00	49.42	39.57	56.90
V	0.92	0.84	0.97	0.89	0.88	0.91	0.88	0.92
D	0.84	0.62	1.02	0.75	0.72	0.81	0.73	0.86
8.	03346000	North Fork Embarras River near Oblong						
Q	4.01	2.01	9.47	4.74	1.70	3.12	2.40	4.37
V	0.37	0.32	0.44	0.38	0.31	0.35	0.33	0.37
D	0.46	0.35	0.64	0.49	0.33	0.42	0.38	0.47
9.	03379500	Little Wabash River below Clay City						
Q	15.50	7.75	38.50	19.30	6.66	10.00	9.20	14.90
V	0.73	0.60	0.94	0.77	0.57	0.64	0.63	0.72
D	0.71	0.52	1.06	0.78	0.49	0.59	0.56	0.70
10.	03380500	Skillet Fork at Wayne City						
Q	1.84	0.92	7.78	3.89	0.74	1.21	1.27	2.17
V	0.37	0.27	0.70	0.51	0.25	0.31	0.31	0.40
D	0.33	0.27	0.51	0.41	0.26	0.30	0.30	0.35
11.	03381500	Little Wabash River at Carmi						
Q	63.90	32.00	123.00	61.50	24.00	36.00	29.93	49.76
V	0.87	0.64	1.15	0.85	0.56	0.67	0.62	0.78
D	1.03	0.85	1.24	1.02	0.78	0.87	0.83	0.96

TABLE 2. CONTINUED

	Values for Q, V, & D for conditions*							
ITEM	C1	C2	C3	C4	C5	C6	C7	C8
12.	03612000	Cache River at Forman						
Q	2.42	1.21	9.90	4.95	0.68	1.25	1.48	2.80
V	0.41	0.31	0.71	0.54	0.25	0.32	0.34	0.43
D	0.46	0.36	0.76	0.59	0.29	0.36	0.39	0.48
13.	05415500	E. F. Galena River at Council Hill						
Q	4.34	2.17	5.77	2.89	2.94	3.48	3.19	3.62
V	0.61	0.47	0.67	0.52	0.53	0.56	0.54	0.57
D	0.60	0.58	0.61	0.59	0.59	0.60	0.59	0.60
14.	05419000	Apple River near Hanover						
Q	39.70	19.90	49.20	24.60	29.73	33.16	30.21	33.85
V	0.63	0.48	0.69	0.52	0.56	0.59	0.57	0.59
D	2.23	1.60	2.48	1.77	1.94	2.05	1.96	2.07
15.	05420000	Plum River below Carroll Ck. near Savanna						
Q	29.20	14.60	39.80	19.90	17.74	21.63	19.59	23.00
V	0.65	0.38	0.82	0.48	0.44	0.52	0.48	0.54
D	0.90	0.82	0.94	0.85	0.84	0.86	0.85	0.87
16.	05435500	Pecatonica River at Freeport						
Q	390.00	195.00	437.00	219.00	292.00	326.00	300.00	332.00
V	0.76	0.54	0.80	0.57	0.66	0.69	0.67	0.70
D	4.48	3.26	4.70	3.44	3.92	4.12	3.97	4.15
17.	05437000	Pecatonica River at Shirland						
Q	705.00	353.00	787.00	394.00	594.00	625.00	576.00	617.00
V	0.89	0.72	0.91	0.75	0.84	0.85	0.83	0.85
D	2.93	1.95	3.12	2.08	2.65	2.73	2.60	2.71
18.	05437500	Rock River at Rockton						
Q	1454.00	727.00	1779.00	890.00	1103.00	1235.00	1164.00	1309.00
V	1.71	1.24	1.87	1.36	1.50	1.58	1.54	1.63
D	1.80	1.29	1.99	1.42	1.58	1.67	1.62	1.71
19.	05438250	Coon Creek at Riley						
Q	8.85	4.43	11.20	5.60	5.28	6.85	6.40	8.10
V	0.76	0.47	0.89	0.55	0.53	0.63	0.61	0.71
D	0.60	0.51	0.63	0.54	0.53	0.56	0.55	0.59
20.	05438500	Kishwaukee River at Belvidere						
Q	73.70	36.90	92.00	46.00	57.22	64.36	59.65	68.57
V	0.99	0.80	1.06	0.86	0.92	0.95	0.93	0.97
D	0.90	0.64	1.01	0.71	0.79	0.84	0.81	0.87
21.	05439500	S. B. Kishwaukee River near Fairdale						
Q	20.10	10.10	28.60	14.30	15.73	18.78	16.22	19.66
V	0.82	0.69	0.90	0.76	0.77	0.81	0.78	0.82
D	0.64	0.50	0.73	0.57	0.59	0.63	0.59	0.64
22.	05440000	Kishwaukee River near Perryville						
Q	138.00	69.00	156.00	78.00	107.00	121.00	111.00	128.00
V	0.99	0.81	1.02	0.84	0.92	0.95	0.93	0.97
D	1.11	0.96	1.14	0.98	1.05	1.08	1.06	1.10

TABLE 2. CONTINUED

	Values for Q, V, & D for conditions*							
ITEM	C1	C2	C3	C4	C5	C6	C7	C8
23.	05440500	Killbuck Creek Near Monroe Center						
Q	7.65	3.83	9.21	4.61	5.77	6.86	5.80	6.96
V	0.51	0.33	0.58	0.37	0.43	0.48	0.43	0.48
D	0.51	0.42	0.54	0.44	0.47	0.49	0.47	0.49
24.	05441000	Leaf River at Leaf River						
Q	18.40	9.20	43.40	21.70	14.05	15.51	14.53	16.09
V	1.57	1.49	1.68	1.59	1.54	1.55	1.54	1.56
D	0.53	0.34	0.90	0.58	0.45	0.47	0.45	0.48
25.	05443500	Rock River at Como						
Q	1765.00	883.00	1923.00	962.00	1379.00	1557.00	1487.00	1670.00
V	1.64	1.11	1.72	1.16	1.43	1.53	1.49	1.60
D	2.26	1.77	2.33	1.82	2.07	2.16	2.13	2.21
26.	05444000	Elkhorn Creek near Penrose						
Q	32.60	16.30	35.60	17.80	22.12	24.89	22.75	25.82
V	0.92	0.71	0.95	0.74	0.80	0.83	0.81	0.84
D	0.87	0.65	0.91	0.67	0.74	0.78	0.75	0.79
27.	05445500	Rock Creek near Morrison						
Q	22.90	11.50	28.20	14.10	19.42	20.84	19.91	21.87
V	0.40	0.24	0.47	0.28	0.36	0.38	0.36	0.39
D	1.03	0.91	1.06	0.94	1.00	1.01	1.00	1.02
28.	05446500	Rock River near Joslin						
Q	2137.00	1069.00	2502.00	1251.00	1725.00	1929.00	1813.00	2015.00
V	1.43	1.17	1.50	1.23	1.35	1.39	1.37	1.41
D	2.43	1.52	2.70	1.69	2.10	2.26	2.17	2.33
29.	05447000	Green River at Amboy						
Q	13.60	6.80	15.60	7.80	10.16	12.27	9.82	11.81
V	0.92	0.67	0.99	0.71	0.81	0.88	0.79	0.87
D	0.67	0.56	0.70	0.58	0.62	0.70	0.62	0.65
30.	05447500	Green River near Geneseo						
Q	106.00	53.00	128.00	64.00	86.00	100.00	87.11	101.00
V	0.94	0.72	1.01	0.77	0.86	0.92	0.87	0.92
D	0.93	0.88	0.95	0.90	0.92	0.93	0.92	0.93
31.	05448000	Mill Creek at Milan						
Q	2.98	1.49	4.99	2.50	1.28	2.02	1.37	2.11
V	0.51	0.41	0.61	0.49	0.39	0.45	0.40	0.46
D	0.34	0.26	0.41	0.32	0.25	0.29	0.25	0.30
32.	05466000	Edwards River near Orion						
Q	8.85	4.43	13.80	6.90	4.76	6.97	5.21	7.38
V	0.61	0.50	0.69	0.56	0.51	0.57	0.52	0.58
D	0.53	0.43	0.60	0.49	0.44	0.49	0.45	0.50
33.	05466500	Edwards River near New Boston						
Q	28.00	14.00	43.20	21.60	18.22	24.29	18.69	24.50
V	0.96	0.81	1.06	0.90	0.86	0.93	0.87	0.93
D	0.57	0.38	0.73	0.49	0.44	0.52	0.45	0.53

TABLE 2. CONTINUED

		Values for Q, V, & D for conditions*						
ITEM	C1	C2	C3	C4	C5	C6	C7	C8
34.	05467000	Pope Creek near Keithsburg						
Q	8.77	4.39	15.60	7.80	5.49	7.51	5.90	7.80
V	0.57	0.44	0.71	0.55	0.48	0.54	0.49	0.55
D	0.45	0.32	0.59	0.42	0.36	0.41	0.37	0.42
35.	05467500	Henderson Creek near Little York						
Q	3.43	1.72	8.77	4.39	1.42	2.52	2.10	3.35
V	0.90	0.81	1.05	0.94	0.78	0.86	0.83	0.90
D	0.39	0.33	0.49	0.41	0.31	0.36	0.34	0.39
36.	05468500	Cedar Creek at Little York						
Q	12.60	6.30	17.60	8.80	9.16	10.92	9.09	10.82
V	0.73	0.61	0.79	0.67	0.67	0.70	0.67	0.70
D	0.98	0.82	1.06	0.89	0.90	0.94	0.90	0.94
37.	05469000	Henderson Creek near Oquawka						
Q	19.60	9.80	35.50	17.80	13.94	18.54	16.00	20.84
V	0.43	0.30	0.59	0.41	0.36	0.42	0.39	0.44
D	1.25	1.12	1.38	1.23	1.18	1.24	1.21	1.27
38.	05495500	Bear Creek near Marcelline						
Q	2.65	1.33	9.11	4.56	0.72	1.37	0.88	1.63
V	0.50	0.42	0.69	0.58	0.36	0.43	0.38	0.45
D	0.28	0.19	0.52	0.36	0.14	0.20	0.16	0.22
39.	05510500	Hadley Creek at Kinderhook						
Q	1.52	0.76	4.50	2.25	0.19	0.53	0.58	1.16
V	0.64	0.55	0.82	0.70	0.40	0.50	0.51	0.60
D	0.25	0.19	0.38	0.29	0.11	0.16	0.17	0.22
40.	05512500	Bay Creek at Pittsfield						
Q	0.53	0.27	1.91	0.96	0.15	0.23	0.20	0.30
V	0.59	0.48	0.87	0.70	0.40	0.46	0.44	0.49
D	0.19	0.15	0.28	0.22	0.13	0.15	0.14	0.16
41.	05513000	Bay Creek at Nebo						
Q	3.62	1.81	10.50	5.25	0.69	1.50	1.13	2.38
V	0.92	0.80	1.15	1.00	0.66	0.77	0.73	0.85
D	0.39	0.33	0.53	0.44	0.25	0.31	0.29	0.35
42.	05520000	Singleton Ditch at Illinoi						
Q	30.60	15.30	36.40	18.20	24.27	28.68	27.08	32.40
V	0.36	0.20	0.41	0.23	0.30	0.34	0.32	0.38
D	1.58	1.46	1.61	1.49	1.54	1.57	1.56	1.59
43.	05520500	Kankakee River at Momence						
	655.00	328.00	744.00	372.00	569.00	622.00	626.00	704.00
V	1.10	0.80	1.16	0.85	1.03	1.07	1.07	1.13
D	1.50	1.11	1.58	1.17	1.41	1.46	1.47	1.54
44.	05525000	Iroquois River at Iroquois						
Q	37.10	18.60	48.80	24.40	22.25	28.75	27.17	39.00
V	0.53	0.44	0.58	0.48	0.46	0.50	0.49	0.54
D	1.18	0.82	1.36	0.94	0.90	1.03	1.00	1.21

TABLE 2. CONTINUED

	Values for Q, V, & D for conditions*							
ITEM	C1	C2	C3	C4	C5	C6	C7	C8
45.	05525500	Sugar Creek at Milford						
Q	14.20	7.10	22.80	11.40	8.53	11.34	10.05	14.39
V	0.94	0.75	1.10	0.88	0.80	0.88	0.84	0.95
D	0.59	0.46	0.69	0.54	0.49	0.54	0.52	0.59
46.	05526000	Iroquois River near Chebanse						
Q	79.40	39.70	110.00	55.00	51.36	65.37	69.44	96.78
V	0.49	0.29	0.63	0.37	0.36	0.43	0.44	0.57
D	0.60	0.53	0.64	0.56	0.55	0.58	0.59	0.62
47.	05526500	Terry Creek near Custer Park						
Q	0.78	0.39	1.40	0.70	0.49	0.77	0.73	1.07
V	0.53	0.70	0.42	0.55	0.64	0.53	0.54	0.47
D	0.29	0.20	0.40	0.27	0.22	0.29	0.28	0.34
48.	05527000	Kankakee River at Custer Park						
Q	710.00	355.00	796.00	398.00	615.00	671.00	685.00	795.00
V	0.52	0.30	0.57	0.33	0.46	0.50	0.50	0.57
D	3.00	2.70	3.05	2.75	2.93	2.97	2.98	3.05
49.	05527500	Kankakee River near Wilmington						
Q	824.00	412.00	949.00	475.00	704.00	797.00	796.00	926.00
V	1.06	0.78	1.13	0.83	0.99	1.05	1.05	1.12
D	1.16	0.96	1.21	1.00	1.11	1.15	1.15	1.20
50.	05529000	Des Plaines River near Des Plaines						
Q	13.80	6.90	19.20	9.60	5.23	8.13	6.20	9.90
V	0.91	1.03	0.86	0.97	1.09	1.00	1.05	0.97
D	0.48	0.38	0.54	0.43	0.34	0.40	0.36	0.43
51.	05531000	Salt Creek near Arlington Heights						
Q	0.88	0.44	1.76	0.88	0.28	0.54	0.37	0.77
V	0.60	0.54	0.67	0.60	0.51	0.56	0.53	0.59
D	0.27	0.21	0.35	0.27	0.18	0.23	0.20	0.26
52.	05531500	Salt Creek at Western Springs						
Q	16.90	8.45	23.60	11.80	6.37	10.20	8.96	13.38
V	0.74	0.65	0.78	0.69	0.62	0.67	0.66	0.71
D	0.75	0.67	0.78	0.71	0.65	0.69	0.70	0.72
53.	05532000	Addison Creek at Bellwood						
Q	3.49	1.75	5.13	2.57	1.09	1.64	1.58	2.21
V	0.46	0.31	0.57	0.39	0.24	0.30	0.30	0.36
D	0.51	0.40	0.59	0.46	0.33	0.39	0.38	0.43
54.	05532500	Des Plaines River at Riverside						
Q	47.40	23.70	74.80	37.40	18.62	28.19	22.56	31.96
V	0.77	0.55	0.97	0.69	0.49	0.60	0.54	0.64
D	0.83	0.64	0.98	0.76	0.58	0.68	0.63	0.71
55.	05533000	Flag Creek near Willow Springs						
Q	4.66	2.33	5.60	2.80	3.59	4.03	3.52	3.96
V	0.63	0.51	0.67	0.54	0.58	0.60	0.58	0.60
D	0.56	0.44	0.60	0.47	0.51	0.53	0.51	0.53

TABLE 2. CONTINUED

		Values for Q, V, & D for conditions*						
ITEM	C1	C2	C3	C4	C5	C6	C7	C8
56.	05533500	Des Plaines River at Lemont						
Q	16.20	8.10	26.60	13.30	8.82	13.37	14.05	19.83
V	0.22	0.17	0.27	0.20	0.17	0.20	0.21	0.24
D	0.53	0.42	0.62	0.49	0.43	0.49	0.50	0.56
57.	05535000	Skokie River at Lake Forest						
Q	2.58	1.29	2.97	1.49	1.65	1.97	1.66	2.01
V	0.67	0.53	0.71	0.55	0.57	0.61	0.58	0.62
D	0.43	0.33	0.46	0.35	0.37	0.39	0.37	0.39
58.	05535500	W. F. of N. B. Chicago River at Northbrook						
Q	2.38	1.19	3.15	1.58	1.02	1.44	1.01	1.43
V	0.64	0.51	0.71	0.56	0.48	0.54	0.48	0.54
D	0.40	0.29	0.45	0.33	0.27	0.31	0.27	0.31
59.	05536000	North Branch Chicago River at Niles						
Q	13.20	6.60	21.30	10.70	7.10	9.23	7.95	10.27
V	0.58	0.46	0.68	0.54	0.47	0.52	0.49	0.54
D	0.71	0.50	0.91	0.64	0.52	0.59	0.55	0.62
60.	05536215	Thorn Creek at Glenwood						
Q	17.70	8.85	19.80	9.90	13.89	15.13	14.17	15.43
V	1.03	0.91	1.05	0.93	0.99	1.00	0.99	1.01
D	0.68	0.46	0.73	0.49	0.59	0.62	0.60	0.63
61.	05536235	Deer Creek near Chicago Heights						
Q	1.10	0.55	1.89	0.95	0.72	0.99	0.90	1.19
V	0.60	0.42	0.80	0.56	0.48	0.57	0.54	0.63
D	0.30	0.26	0.35	0.29	0.27	0.30	0.29	0.31
62.	05536255	Butterfield Creek at Flossmoor						
Q	1.09	0.55	1.52	0.76	0.51	0.76	0.61	0.87
V	0.82	0.69	0.89	0.75	0.67	0.75	0.70	0.77
D	0.22	0.21	0.23	0.22	0.21	0.22	0.21	0.22
63.	05536265	Lansing Ditch near Lansing						
Q	1.47	0.74	1.74	0.87	0.55	0.78	0.43	0.72
V	0.16	0.10	0.18	0.11	0.08	0.10	0.07	0.10
D	0.84	0.73	0.87	0.75	0.68	0.74	0.65	0.72
64.	05536270	North Creek near Lansing						
Q	1.74	0.87	2.25	1.13	0.59	0.90	0.54	0.92
V	0.27	0.23	0.29	0.24	0.21	0.23	0.20	0.23
D	0.37	0.24	0.43	0.28	0.19	0.24	0.18	0.25
65.	05536275	Thorn Creek at Thornton						
Q	24.80	12.40	31.30	15.70	18.45	21.11	19.18	22.41
V	0.84	0.59	0.95	0.67	0.72	0.78	0.74	0.80
D	0.97	0.82	1.03	0.87	0.90	0.93	0.91	0.95
66.	05536290	Little Calumet River at South Holland						
Q	36.90	18.50	49.90	25.00	30.38	33.74	32.18	36.34
V	0.56	0.47	0.61	0.51	0.53	0.55	0.54	0.56
D	1.46	1.09	1.65	1.24	1.34	1.40	1.38	1.45

TABLE 2. CONTINUED

		Values for Q, V, & D for conditions*						
ITEM	C1	C2	C3	C4	C5	C6	C7	C8
67.	05536340	Midlothian Creek at Oak Forest						
Q	0.49	0.25	0.90	0.45	0.20	0.33	0.30	0.49
V	0.26	0.19	0.35	0.25	0.17	0.22	0.21	0.26
D	0.36	0.30	0.43	0.35	0.28	0.32	0.31	0.36
68.	05539000	Hickory Creek at Joliet						
Q	7.19	3.60	9.40	4.70	5.83	6.81	6.52	7.87
V	0.33	0.23	0.38	0.27	0.30	0.32	0.32	0.35
D	0.46	0.37	0.51	0.40	0.43	0.46	0.45	0.48
69.	05539900	W. B. Du Page River near West Chicago						
Q	7.09	3.55	9.48	4.74	2.50	3.80	3.00	4.68
V	0.71	0.59	0.76	0.64	0.55	0.61	0.57	0.64
D	0.83	0.60	0.95	0.68	0.51	0.62	0.55	0.68
70.	05540500	Du Page River at Shorewood						
Q	49.40	24.70	61.40	30.70	40.10	44.70	39.40	44.89
V	0.84	0.62	0.93	0.68	0.77	0.81	0.76	0.81
D	0.67	0.48	0.74	0.53	0.60	0.63	0.60	0.64
71.	05542000	Mazon River near Coal City						
Q	2.14	1.07	4.90	2.45	0.74	1.59	1.00	1.88
V	0.36	0.28	0.48	0.38	0.25	0.32	0.28	0.34
D	0.33	0.27	0.40	0.34	0.25	0.30	0.27	0.32
72.	05543500	Illinois River at Marseilles						
Q	4643.00	2322.00	4967.00	2484.00	4445.00	4729.00	4342.00	4647.00
V	2.99	2.10	3.09	2.17	2.92	3.01	2.89	2.99
D	2.31	1.62	2.39	1.67	2.26	2.33	2.23	2.31
73.	05549000	Boone Creek near McHenry						
Q	5.80	2.90	6.47	3.24	4.99	5.49	5.33	5.93
V	1.03	0.69	1.10	0.73	0.94	1.00	0.98	1.04
D	0.49	0.40	0.51	0.41	0.47	0.48	0.48	0.50
74.	05550000	Fox River at Algonquin						
Q	169.00	84.50	214.00	107.00	119.00	145.00	164.00	201.00
V	1.32	0.97	1.46	1.08	1.13	1.23	1.30	1.42
D	0.99	0.78	1.07	0.84	0.87	0.94	0.98	1.05
75.	05550500	Poplar Creek at Elgin						
Q	1.64	0.82	2.28	1.14	0.80	1.11	0.95	1.25
V	0.44	0.42	0.45	0.43	0.42	0.43	0.42	0.43
D	0.37	0.30	0.41	0.33	0.30	0.33	0.32	0.34
76.	05551200	Ferson Creek near St. Charles						
Q	4.94	2.47	6.35	3.18	1.89	2.72	2.82	4.07
V	0.71	0.60	0.75	0.64	0.56	0.61	0.62	0.68
D	0.47	0.39	0.50	0.42	0.37	0.40	0.40	0.44
77.	05551700	Blackberry Creek near Yorkville						
Q	9.10	4.55	10.80	5.40	8.20	9.25	8.80	10.24
V	0.81	0.57	0.88	0.62	0.77	0.82	0.80	0.86
D	0.68	0.56	0.71	0.59	0.66	0.68	0.67	0.70

TABLE 2. CONTINUED

	Values for Q, V, & D for conditions*							
ITEM	C1	C2	C3	C4	C5	C6	C7	C8
78.	05552500	Fox River at Dayton						
Q	350.00	175.00	415.00	208.00	269.00	314.00	327.00	389.00
V	1.28	0.96	1.37	1.03	1.15	1.22	1.24	1.34
D	1.63	1.34	1.71	1.41	1.51	1.58	1.60	1.70
79.	05554000	N. F. Vermilion River near Charlotte						
Q	1.09	0.55	2.16	1.08	0.49	0.83	0.73	1.31
V	0.23	0.22	0.24	0.23	0.22	0.22	0.22	0.23
D	0.21	0.15	0.29	0.21	0.14	0.18	0.17	0.23
80.	05554500	Vermilion River at Pontiac						
Q	6.26	3.13	9.97	4.99	4.31	6.70	5.77	8.22
V	0.23	0.15	0.30	0.20	0.19	0.24	0.22	0.27
D	0.54	0.48	0.59	0.52	0.51	0.55	0.54	0.57
81.	05555500	Vermilion River at Lowell						
Q	17.90	8.95	26.20	13.10	13.92	17.93	15.37	20.90
V	0.41	0.32	0.47	0.37	0.38	0.41	0.39	0.44
D	0.70	0.58	0.77	0.64	0.65	0.70	0.67	0.73
82.	05556500	Bureau Creek at Princeton						
Q	3.03	1.52	6.13	3.07	2.44	3.36	2.62	3.56
V	0.45	0.32	0.64	0.46	0.41	0.48	0.42	0.49
D	0.41	0.36	0.47	0.41	0.40	0.42	0.40	0.43
83.	05558500	Crow Creek (West) near Henry						
Q	1.05	0.53	1.79	0.90	0.35	0.57	0.36	0.65
V	0.61	0.57	0.65	0.60	0.54	0.57	0.54	0.58
D	0.28	0.24	0.33	0.27	0.21	0.24	0.21	0.25
84.	05560500	Farm Creek at Farmdale						
Q	1.01	0.51	1.50	0.75	0.39	0.61	0.51	0.77
V	0.54	0.40	0.64	0.48	0.36	0.44	0.40	0.48
D	0.25	0.20	0.28	0.22	0.18	0.21	0.20	0.23
85.	05562000	Farm Creek at East Peoria						
Q	2.60	1.30	3.92	1.96	1.79	2.10	1.55	2.05
V	0.91	0.74	1.03	0.84	0.81	0.85	0.78	0.85
D	0.19	0.17	0.20	0.18	0.18	0.18	0.17	0.18
86.	05563000	Kickapoo Creek near Kickapoo						
Q	3.76	1.88	7.65	3.83	2.46	3.09	2.94	3.93
V	0.86	0.73	1.02	0.86	0.78	0.82	0.81	0.87
D	0.30	0.22	0.41	0.31	0.25	0.28	0.27	0.31
87.	05563500	Kickapoo Creek at Peoria						
Q	9.69	4.85	21.20	10.60	5.87	7.83	7.53	9.76
V	0.62	0.46	0.85	0.64	0.50	0.56	0.56	0.62
D	0.53	0.44	0.66	0.54	0.46	0.50	0.49	0.53
88.	05567500	Mackinaw River near Congerville						
Q	13.00	6.50	21.60	10.80	9.43	12.89	11.12	15.56
V	0.74	0.44	1.08	0.64	0.58	0.74	0.66	0.85
D	0.53	0.46	0.59	0.51	0.50	0.53	0.52	0.55

TABLE 2. CONTINUED

	Values for Q, V, & D for conditions*							
ITEM	C1	C2	C3	C4	C5	C6	C7	C8
89.	05568000	Mackinaw River near Green Valley						
Q	56.50	28.30	70.60	35.30	44.71	52.87	43.79	52.77
V	1.49	2.06	1.35	1.86	1.66	1.54	1.68	1.54
D	0.69	0.39	0.84	0.47	0.57	0.66	0.56	0.66
90.	05568500	Illinois River at Kingston Mines						
Q	5208.00	2604.00	5951.00	2976.00	4790.00	5222.00	4924.00	5472.00
V	0.93	0.66	1.00	0.71	0.90	0.93	0.91	0.96
D	9.51	7.40	9.98	7.77	9.23	9.52	9.32	9.68
91.	05568800	Indian Creek near Wyoming						
Q	4.99	2.50	6.98	3.49	2.14	3.10	2.29	3.42
V	0.73	0.61	0.79	0.67	0.59	0.65	0.60	0.66
D	0.41	0.35	0.44	0.38	0.34	0.37	0.34	0.37
92.	05569500	Spoon River at London Mills						
Q	47.80	23.90	81.90	41.00	31.86	41.96	36.31	48.53
V	0.47	0.38	0.55	0.44	0.41	0.45	0.43	0.47
D	1.44	1.03	1.88	1.34	1.18	1.35	1.26	1.45
93.	05570000	Spoon River at Seville						
Q	85.40	42.70	155.00	77.50	50.15	68.33	57.54	78.00
V	0.99	1.17	0.86	1.02	1.13	1.05	1.09	1.01
D	1.29	0.81	1.90	1.21	0.91	1.11	0.99	1.21
94.	05571000	Sangamon River at Mahomet						
Q	8.78	4.39	11.30	5.65	4.50	6.88	5.90	9.04
V	0.75	0.56	0.83	0.62	0.56	0.67	0.63	0.76
D	0.40	0.37	0.41	0.38	0.37	0.39	0.38	0.40
95.	05572000	Sangamon River at Monticello						
Q	15.00	7.50	22.00	11.00	9.82	13.19	11.73	16.53
V	0.56	0.53	0.58	0.55	0.55	0.56	0.55	0.57
D	0.65	0.49	0.75	0.57	0.54	0.61	0.58	0.67
96.	05574500	Flat Branch near Taylorville						
Q	3.52	1.76	8.17	4.08	1.02	2.90	2.04	3.90
V	0.44	0.33	0.61	0.47	0.27	0.41	0.35	0.46
D	0.57	0.49	0.69	0.59	0.43	0.55	0.51	0.58
97.	05575500	South Fork Sangamon River at Kincaid						
Q	11.30	5.65	19.60	9.80	4.13	7.50	5.30	9.00
V	0.66	0.50	0.82	0.62	0.45	0.56	0.49	0.60
D	0.51	0.49	0.53	0.51	0.48	0.50	0.49	0.51
98.	05576000	South Fork Sangamon River near Rochester						
Q	16.20	8.10	37.80	18.90	8.00	14.41	10.27	18.20
V	0.65	0.50	0.88	0.68	0.50	0.62	0.54	0.67
D	0.78	0.64	1.00	0.82	0.64	0.76	0.69	0.81
99.	05576500	Sangamon River at Riverton						
Q	66.90	33.50	111.00	55.50	48.64	62.61	47.56	65.30
V	0.85	0.62	1.09	0.78	0.73	0.83	0.73	0.84
D	1.32	1.10	1.50	1.25	1.21	1.29	1.20	1.31

TABLE 2. CONTINUED

	Values for Q, V, & D for conditions*							
ITEM	C1	C2	C3	C4	C5	C6	C7	C8
100.	05578500	Salt Creek near Rowell						
Q	14.00	7.00	19.40	9.70	8.34	11.56	11.00	15.11
V	0.75	0.67	0.79	0.70	0.69	0.72	0.72	0.76
D	0.52	0.44	0.56	0.47	0.46	0.49	0.49	0.53
101.	05579500	Lake Fork near Cornland						
Q	9.82	4.91	10.80	5.40	6.92	8.57	6.63	8.51
V	0.63	0.45	0.67	0.47	0.53	0.59	0.52	0.59
D	0.46	0.40	0.47	0.41	0.43	0.45	0.42	0.45
102.	05580000	Kickapoo Creek at Waynesville						
Q	7.37	3.69	12.40	6.20	3.04	5.26	3.94	6.40
V	0.74	0.63	0.82	0.71	0.61	0.68	0.64	0.71
D	0.59	0.48	0.69	0.56	0.45	0.53	0.49	0.57
103.	05580500	Kickapoo Creek near Lincoln						
Q	10.20	5.10	18.00	9.00	7.19	9.80	7.37	9.96
V	0.70	0.56	0.83	0.67	0.63	0.69	0.63	0.69
D	0.56	0.46	0.67	0.54	0.51	0.56	0.51	0.56
104.	05581500	Sugar Creek near Hartsburg						
Q	17.70	8.85	27.20	13.60	13.55	16.32	14.67	18.65
V	0.77	0.58	0.92	0.69	0.69	0.74	0.71	0.79
D	0.54	0.48	0.58	0.52	0.52	0.53	0.53	0.55
105.	05582000	Salt Creek near Greenview						
Q	148.00	74.00	176.00	88.00	116.00	137.00	115.00	137.00
V	1.38	1.01	1.50	1.09	1.24	1.33	1.23	1.33
D	1.05	0.85	1.11	0.89	0.97	1.02	0.97	1.02
106.	05582500	Crane Creek near Easton						
Q	4.29	2.15	5.38	2.69	2.44	3.27	3.81	4.88
V	0.37	0.30	0.40	0.32	0.31	0.34	0.36	0.38
D	0.70	0.60	0.73	0.63	0.62	0.66	0.68	0.72
107.	05583000	Sangamon River near Oakford						
Q	389.00	195.00	570.00	285.00	305.00	376.00	291.00	351.00
V	1.32	1.09	1.47	1.21	1.23	1.31	1.22	1.28
D	1.17	0.88	1.37	1.03	1.06	1.15	1.04	1.12
108.	05584500	La Moine River at Colmar						
Q	19.30	9.65	42.60	21.30	8.67	13.56	10.17	15.59
V	0.81	0.71	0.96	0.83	0.69	0.76	0.71	0.78
D	0.80	0.63	1.06	0.83	0.61	0.71	0.64	0.75
109.	05585000	La Moine River at Ripley						
Q	52.20	26.10	104.00	52.00	25.95	36.30	28.10	38.52
V	1.40	1.42	1.38	1.40	1.42	1.41	1.42	1.41
D	1.28	0.95	1.73	1.28	0.95	1.09	0.98	1.12
110.	05585500	Illinois River at Meredosia						
Q	6367.00	3184.00	7384.00	3692.00	5980.00	6593.00	6176.00	6938.00
V	1.04	0.76	1.11	0.81	1.01	1.05	1.02	1.08
D	8.01	5.71	8.61	6.14	7.77	8.15	7.89	8.35

TABLE 2. CONTINUED

Values for Q, V, & D for conditions*

ITEM	C1	C2	C3	C4	C5	C6	C7	C8
111.	05587000	Macoupin Creek near Kane						
Q	15.70	7.85	38.30	19.20	6.93	9.84	7.24	10.28
V	0.85	0.70	1.09	0.90	0.68	0.75	0.69	0.76
D	0.45	0.38	0.56	0.48	0.37	0.40	0.37	0.41
112.	05589500	Canteen Creek at Caseyville						
Q	0.87	0.44	1.67	0.84	0.35	0.49	0.50	0.69
V	0.65	0.61	0.69	0.65	0.60	0.62	0.62	0.64
D	0.22	0.16	0.30	0.22	0.14	0.17	0.17	0.20
113.	05590000	Kaskaskia River at Bondville						
Q	0.32	0.16	0.48	0.24	0.19	0.28	0.24	0.37
V	0.40	0.33	0.45	0.37	0.35	0.39	0.37	0.42
D	0.15	0.11	0.18	0.13	0.11	0.14	0.13	0.16
114.	05592000	Kaskaskia River at Shelbyville						
Q	13.40	6.70	25.90	13.00	7.15	11.88	9.06	14.77
V	0.86	0.73	1.00	0.85	0.74	0.84	0.79	0.88
D	0.44	0.31	0.63	0.44	0.32	0.42	0.36	0.47
115.	05592500	Kaskaskia River at Vandalia						
Q	62.80	31.40	110.00	55.00	41.34	56.59	47.13	66.24
V	0.60	0.48	0.72	0.58	0.53	0.58	0.55	0.61
D	1.68	1.19	2.21	1.57	1.36	1.59	1.46	1.72
116.	05593000	Kaskaskia River at Carlyle						
Q	82.30	41.20	189.00	94.50	56.74	76.72	58.90	79.88
V	0.73	0.62	0.90	0.76	0.67	0.72	0.68	0.73
D	1.07	0.70	1.81	1.17	0.85	1.03	0.87	1.05
117.	05594000	Shoal Creek near Breese						
Q	16.80	8.40	38.90	19.50	9.63	13.38	11.78	16.17
V	0.58	0.47	0.75	0.61	0.49	0.55	0.53	0.58
D	0.80	0.58	1.18	0.86	0.61	0.72	0.68	0.79
118.	05595000	Kaskaskia River at New Athens						
Q	180.00	90.00	339.00	170.00	140.00	188.00	149.00	202.00
V	0.42	0.31	0.56	0.41	0.38	0.43	0.39	0.45
D	3.11	2.31	4.08	3.03	2.79	3.17	2.86	3.26
119.	05596000	Big Muddy River near Benton						
Q	4.62	2.31	16.30	8.15	1.75	2.71	2.68	4.22
V	0.64	0.53	0.90	0.75	0.49	0.55	0.55	0.62
D	0.40	0.31	0.65	0.50	0.28	0.33	0.32	0.39
120.	05597000	Big Muddy River at Plumfield						
Q	6.68	3.34	21.23	11.62	2.88	4.29	4.61	7.09
V	1.71	1.43	2.31	1.98	1.38	1.53	1.55	1.74
D	0.24	0.19	0.38	0.30	0.18	0.21	0.21	0.25
121.	05599000	Beaucoup Creek near Matthews						
Q	4.10	2.05	9.28	4.64	0.92	1.87	1.59	3.18
V	0.29	0.22	0.41	0.31	0.16	0.21	0.20	0.27
D	0.67	0.53	0.87	0.70	0.41	0.52	0.49	0.62

TABLE 2. CONCLUDED

	Values for Q, V, & D for conditions*							
ITEM	C1	C2	C3	C4	C5	C6	C7	C8
122.	05599500	Big Muddy River at Murphysboro						
Q	48.10	24.10	116.00	58.00	31.08	42.38	40.84	59.52
V	1.03	0.74	1.59	1.13	0.83	0.97	0.95	1.15
D	0.78	0.66	0.97	0.82	0.71	0.76	0.75	0.83
123.	05600000	Big Creek near Wetaug						
Q	1.02	0.51	3.23	1.62	0.52	0.81	0.80	1.14
V	0.22	0.16	0.37	0.27	0.16	0.20	0.20	0.23
D	0.50	0.39	0.78	0.60	0.39	0.46	0.46	0.53

*C1 = Median 31-day low flow during the period May-October.

C2 = Half median 31-day low flow during the period May-October.

C3 = Median 61-day low flow during the period May-October.

C4 = Half median 61-day low flow during the period May-October.

C5 = Flow at 90 percent duration using daily flows May-October.

C6 = Flow at 85 percent duration using daily flows May-October.

C7 = Flow at 90 percent duration using daily flows for the record.

C8 = Flow at 85 percent duration using daily flows for the record.

Leopold and Maddock showed that these relationships are valid for different cross sections along the stream, even when the values of a, b, c, f, k, and m change. The relationships were found to be greatly similar and consistent, even for stream systems in different physiographic settings.

Stall and Fok (1968) confirmed the general relationships for Illinois streams. They used the data from 166 gaging stations to develop parameters needed to define the hydraulic geometry of the streams, and presented the results as separate sets of equations for 18 major river basins. The general form of the relationship is:

$$\ln\ (\text{parameter}) = a - bF + c\ \ln A_d$$

in which parameter refers to Q, A (area of flow section), V(= Q/A), W (width of the stream at the surface), and D(= A/W); a, b, and c are coefficients; F and A_d denote flow duration and drainage area in square miles, respectively; and ln represents the natural logarithm. The set of values of a, b, and c for a parameter were developed by considering values of the parameter at 9 values of F (0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, and 0.9) at each of the gaging stations in a major river basin.

Hydraulic Geometry Parameters

The intent was to use the already developed hydraulic geometry equations for calculating hydraulic geometry parameters for Q(90) and Q(85) and for the other 6 flow releases from corresponding F values from flow-duration curves. A preliminary investigation for the gaging stations in the Sangamon River basin revealed that the developed relationships yielded parameter values which were significantly different from those indicated by the actual data.

The hydraulic geometry relationships were significantly improved by dividing the Sangamon basin into 3 sub-basins on the basis of flow duration

(Singh, 1971) and by making a few changes in the structure of the equations. These improved relationships not only indicated better fit over the range of F values, but also yielded considerably lower estimates of standard error.

It was decided to calculate the parameters A, V, W, and D at each gaging station for the discharges corresponding to the 8 low flow release criteria with the following procedure:

1) Plot A, V, W, and D versus Q on logarithmic paper for the range of Q, encompassing all the low flow release values being used as criteria.
2) Draw best-fit straight lines indicating the general relation

$$\log (\text{parameter}) = a + b (\log Q)$$

in which a is the intercept and b is a coefficient.

3) Check that V and A, and D and W relations are compatible in the sense that $V \times A = Q$ and $D \times W = A$.
4) Calculate a set of values of A, V, W, and D for each of the 8 low flow release criteria.

Relevant information was obtained from the U.S. Geological Survey office in Champaign, Illinois, to develop A, V, W, and D versus Q curves for 26 gaging stations to update the information available at the other 97 gaging stations (Singh, 1981). Values of the 3 parameters (Q, V, and D) for each flow release at the 123 stations are given in table 2.

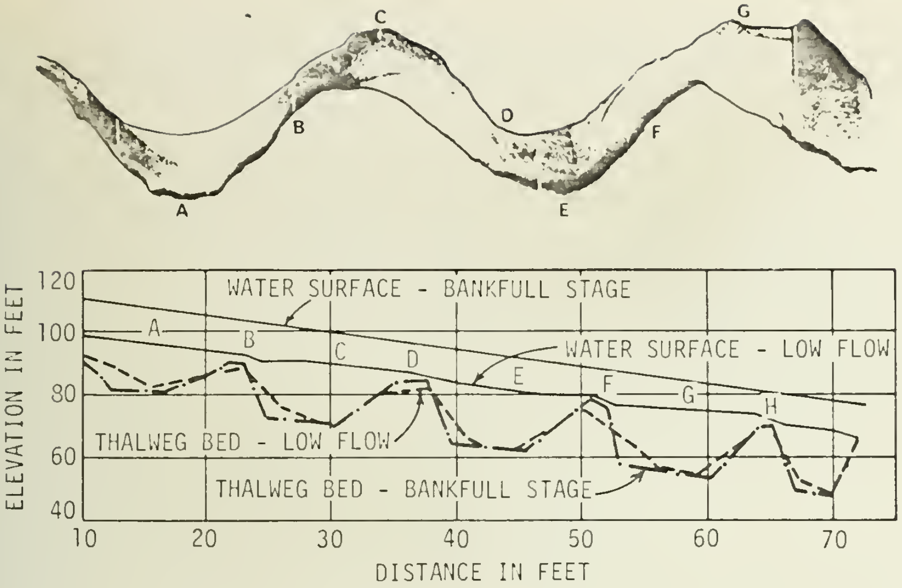
Formation of Riffles and Pools

The lateral deviation of a natural stream from a straight course results in a smooth sinuous or meandering course. A vertical deviation generally results in a concave longitudinal stream bed profile with undulating deeps and shallows, which are usually called pools and riffles, respectively (Yang, 1971). Yang demonstrated the formation of riffles and pools in natural streams as a means of channel self-adjustment that satisfies the law of least time rate of energy expenditure. The fundamental difference between riffles and pools is the difference in energy gradients. In a complete cycle of a pool-riffle sequence, the riffle is defined as the portion that has an energy gradient steeper than the average energy gradient of the complete cycle, whereas the pool is the portion that has an energy gradient milder than the cycle average. The riffles act as submerged dams to slow down the release of water from the pools behind them.

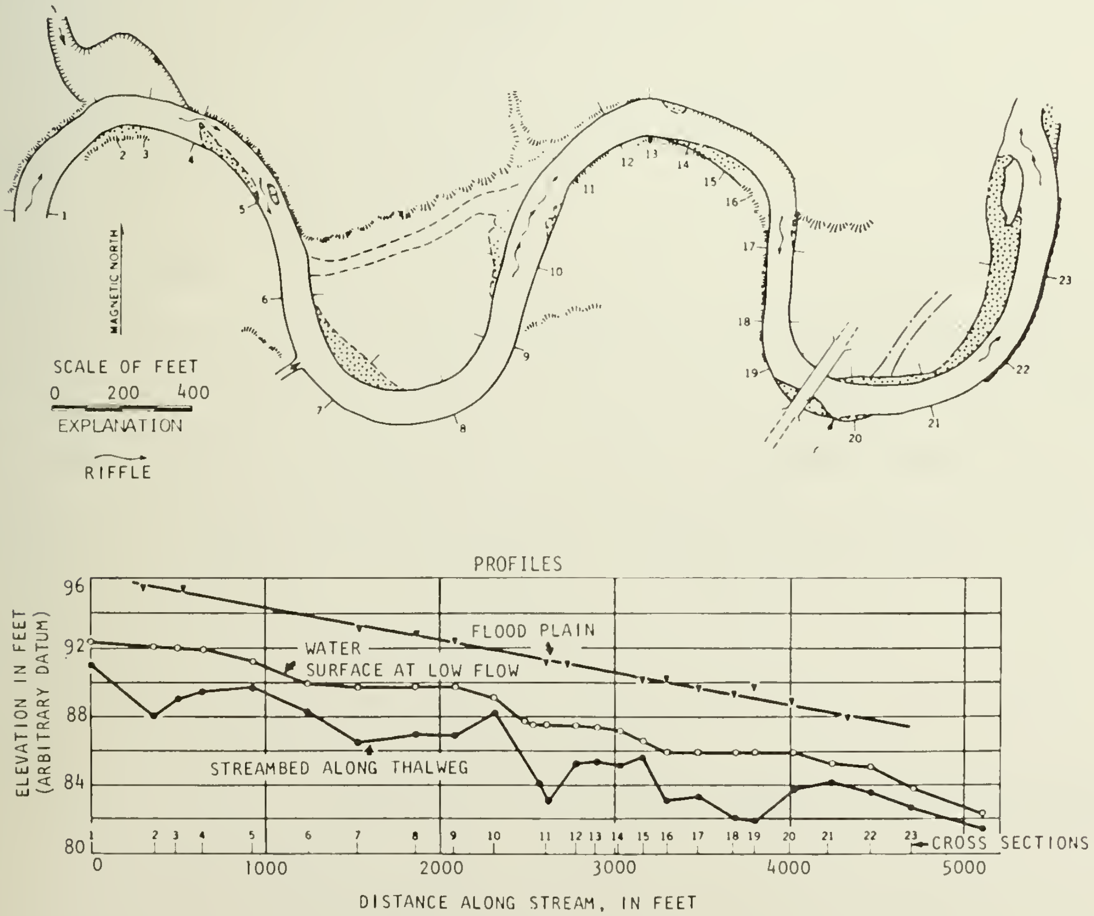
A nonmeandering channel has an undulating bed with deeps and shallows that alternate along its length, spread more or less regularly at a repeating distance equal to 5 to 7 widths (Leopold et al.,1964). The same holds for the meandering channels. The plan and profile of a meandering laboratory channel (Friedkin, 1945) and of a meandering reach of the Popo Agie River near Hudson, Wyoming (Leopold and Wolman, 1957) are shown in figure 2. The crossings are located at the points of inflection (B, D, and F) along the meandering course in figure 2A, and these are the locations for riffles. The pools are located at the bends (A, C, E, and G). Because of the tributaries, obstructions, and various geologic constraints, the location of riffles and pools may not be very precise and the spacing may vary within a reasonable limit.

Hydraulic Geometry Parameters for Pool Conditions

The U.S. Geological Survey usually makes the low flow measurements at the riffles. Thus, the parameters V and D (i.e., velocity and depth) apply to the riffle conditions at the low flows. As the water stage moves from low to high, the water slope difference between pools and riffles disappears. At high flow, the water surface slope is uniform throughout the whole reach.



A. Plan and profile of a meandering laboratory channel (from *Friedkin*, 1945)



B. Plan and profile of a meandering reach of the Popo Agie River near Hudson, Wyoming (after *Leopold and Wolman*, 1957)

Figure 2. Meandering laboratory channel and Popo Agie River

The relative depth of a pool below the riffle bed depends on a number of factors such as the stream order (or the drainage area as its surrogate), the river flow, the bed material, and the flow variations. Three stream profiles for the Little Wabash River 5 miles north of Effingham (drainage area 166 sq mi), for the Clay City gaging station (drainage area 1131 sq mi), and for the area near Hodgson Bridge 4 mi south of Golden Gate (drainage area 1875 sq mi) are given by Herricks et al. (1980). For the first reach and a flow of 8.12 cfs, the average pool depth below the riffle bed is about 2 feet; for the second reach and a flow of 527 cfs, the average pool depth below the riffle is about 2.5 feet; and for the third reach, it is about 2.8 feet. Thus, the average depth of the pool bed below the riffle bed may be approximated by $b \times \log A$ in which b is a coefficient and A is drainage area in sq mi. The coefficient b varies between 0.8 and 0.9 for the above three reaches. To allow for bed level variations along a cross section, a value of 0.75 is adopted for the coefficient in this study. This value seems to be a fair representation of the riffle and pool depths and sequences that could be obtained from the past publications.

The average velocity in the pool, v_p, is obtained from the values of depth and velocity at the riffle, d_r and v_r, with the equation of continuity:

$$d_p = d_r + 0.75 \log A$$

$$v_p = (d_r \times v_r) / d_p$$

in which d_p is the average water depth in the pool.

EVAPORATION AND SEDIMENTATION

The amount of net reservoir storage available for meeting the project purposes can be obtained from the gross reservoir storage after making suitable allowances for net evaporation loss from the reservoir during a design drought and for the storage loss because of the sediment entrapped in the reservoir. Because the occurrence of a design drought cannot be predicted in advance (e.g., a 25-year drought may occur in any year 1 through 25, a 25-year drought may not occur at all in the 25-year period, or a more severe drought may occur in this period), the gross storage provided at the beginning usually equals the sum of storage lost to net evaporation during the design drought, storage lost to sedimentation over the design period, and storage needed to meet project purposes.

Evaporation Loss

Net yield from a reservoir is obtained by subtracting evaporation loss from the gross reservoir storage during the design period of critical drawdown. The net reservoir storage to provide the net yield (taken as 2, 5, 10, or 20 percent of mean flow in this study) depends on the associated risk of getting a lesser yield. In this study, the risk implied is that the net yield may be less than the desired yield once in more than 25 or 40 years.

The daily rainfall records are available for 68 years, 1911-1978, for 9 raingage stations: Chicago, Rockford, Moline, Peoria, Springfield, and Carbondale in Illinois; St. Louis in Missouri; and Evansville and Indianapolis in Indiana. Urbana, Illinois has 49 years of record but this has extended to 68 years (Terstriep et al.,in preparation, 1981). For computing net lake evaporation, two continuous data sets are needed: one for precipitation and the other for lake evaporation. Data for lake evaporation are not directly available, but evaporation pan data at several locations available for about seven months of each year, excluding the winter period, can be used to develop suitable lake evaporation estimates with the methodology described by Roberts and Stall (1967). This has been done in Bulletin 51A (Terstriep et al., in preparation, 1981) in terms of monthly lake evaporations at the 10 raingage stations. The net evaporation each month was obtained by subtracting the monthly precipitation from the monthly evaporation. Thus, net evaporation will be negative in a month in which rainfall exceeds the lake evaporation. Statistical analyses were performed to develop the net evaporation estimates for critical durations of 1 to 60 months and recurrence intervals of 2 to 100 years. The tabulated information in Bulletin 51A was used in this study for considering the compensatory storage for net evaporation losses.

Bulletin 51A provides the information on reservoir yield and associated reservoir storage and critical drawdown duration in months for the design recurrence interval. The storage in inches of runoff can be easily converted to storage in acre-feet (ac-ft). The water surface area in acres, A_w, for the storage in ac-ft, S, is obtained from the following equation (Dawes and Wathne, 1968):

$$A_w = 0.23\ S^{0.87}$$

The evaporation loss in ac-ft, EVL, is obtained from

$$EVL = 0.65\ A_w\ (NEL/12)$$

in which NEL is the net evaporation loss in inches from the lake during the critical drawdown period, and effective surface area for evaporation loss is 65 percent of that at the normal pool because of reduction in water surface area as the water level lowers during the critical period.

Sedimentation

Annual reservoir capacity loss because of sedimentation can be read from a graph (Stall, 1964) when drainage area and reservoir capacity are known. A single equation was fitted to this graph by Singh et al.(1972):

$$\text{Capacity loss} = 0.0191\ A^{-0.1473\ (\log_{10}A)^{0.64}}$$

in which capacity loss is in inches per year and A is the drainage area in square miles. The above equation is independent of the reservoir capacity-inflow ratio which is believed to be a significant parameter for evaluating trap efficiency of the reservoirs (Brune, 1953).

In the Upper Mississippi River Comprehensive Basin Study (UMRCBS, 1970), the stream sediment yield, Y_s, in tons/sq mi/year is given by

$$Y_s = k\ A^{\alpha}$$

in which α is -0.12, A is the drainage area in square miles, and k is a coefficient which varies from one land resource area, LRA, to the other. The state of Illinois was divided into 10 LRAs by the U.S. Department of Agriculture (Austin, 1965). For each LRA, the coefficient k was found from the regression analysis with the log-transformed equation

$$\log Y_s = \log k + \alpha \log A$$

and the available data. The annual sediment yield, for a given drainage area A is obtained by multiplying A and Y_s. To convert this yield into ac-ft per year, the sediment trapped in the reservoir is calculated:

$$\text{Sediment in tons/year} = A \times Y_s \times \text{trap efficiency}$$

in which the trap efficiency equals percent trap efficiency in figure 3, divided by 100.

It is necessary to measure the specific weight of deposited sediments to obtain

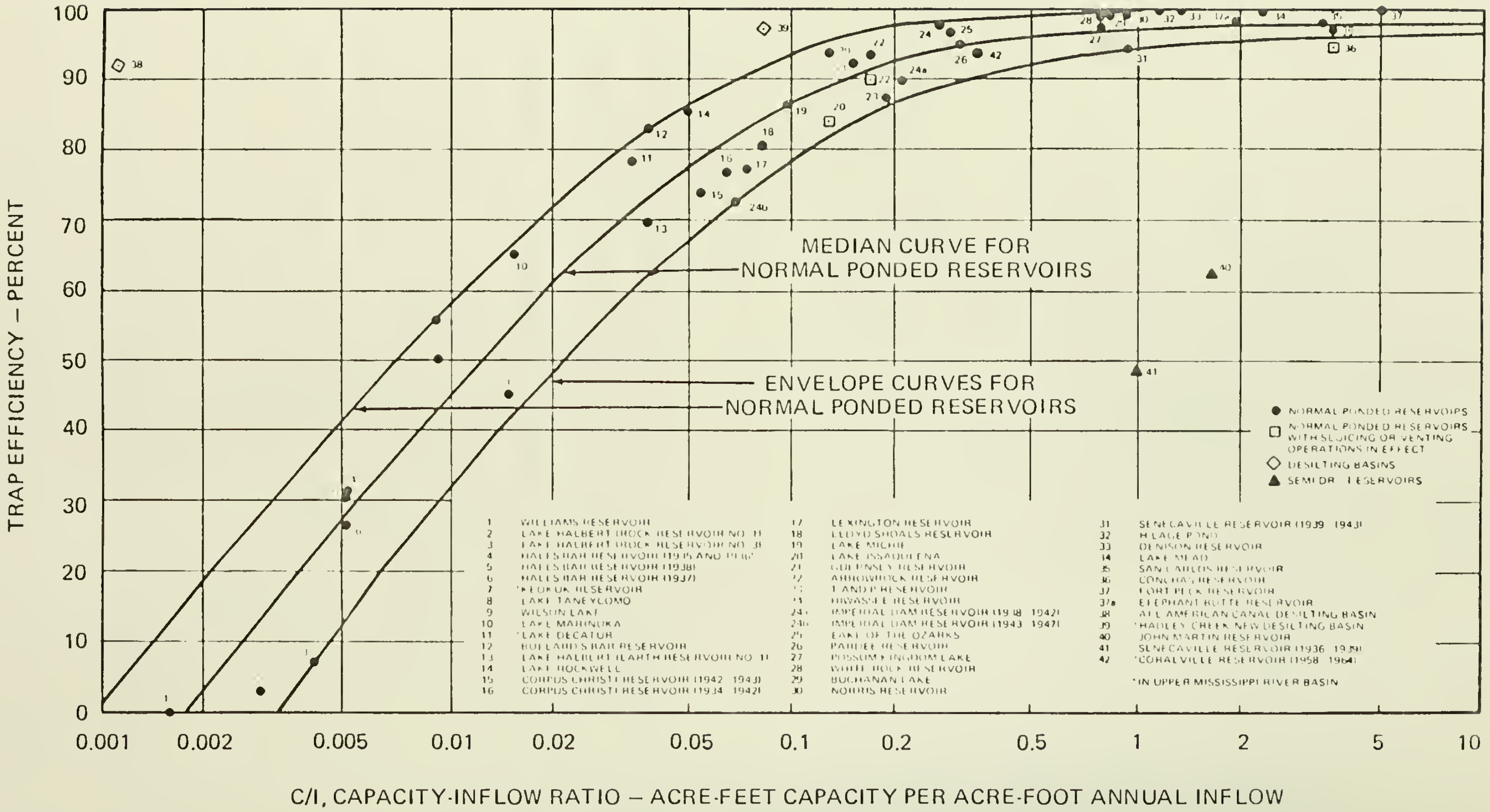


Figure 3. Trap efficiency versus capacity-inflow ratio (after *Brune*, 1953)

the volume of materials deposited in a reservoir. Equations for computing specific weights of reservoir sediments are given in the UMRCBS. For the Illinois condition, the specific weight varies from about 40 to 60 lbs/cu ft.

Available Lake Sedimentation Data

The State Water Survey has been conducting lake sedimentation surveys for more than 40 years. The data on 98 lakes surveyed over the years (see listing in table 3) were analyzed to develop information on the following factors:

Location of lake
Drainage area, sq mi
Average discharge, inches/yr
Average lake capacity, ac-ft and inches
Capacity-inflow ratio, CP/I
Annual sediment rate, ac-ft/yr
Percent capacity reduction

The average lake capacity equals the mean of the capacities for the first and second surveys, and the annual sediment rate equals the loss in reservoir capacity between the two surveys divided by the time interval in years. The capacity-inflow ratio, CP/I, is average lake capacity in inches divided by the average discharge entering the lake in inches/year.

Regional Relations

An effort was made to correlate the percent capacity reduction, PCR, with basin factors (such as drainage area and main channel length and slope) and CP/I. The available data were broken into regional sets to improve the correlations. These analyses showed that the inclusion of basin factors did not

TABLE 3. Illinois Lakes with Sediment Data

	Name of Reservoir	Location
1.	Nelson, Lake No. 4	Millersburg
2.	Lake No. 3	Matherville
3.	Ewan, Pond No. 12	Kewanee
4.	Lake Calhoun	Galva
5.	Armstrong, Pond No. 13	Toulon
6.	Rio, C.B. & Q Reservoir No. 11	Rio
7.	Lake Bracken	Galesburg
8.	Lake Storey	Galesburg
9.	Lake Bloomington	Bloomington
10.	Avon, Reservoir No. 19	Avon
11.	Canton, Lake No. 36	Canton
12.	Van Winkle, Lake No. 18	Canton
13.	Spring, Lake No. 23	Macomb
14.	Carthage, Reservoir No. 26	Carthage
15.	Argyle, Lake No. 25	Colchester
16.	Vermont, Lake No. 24 (new)	Vermont
17.	Astoria, Reservoir No. 21	Astoria
18.	Saukenauk, Lake No. 35	Lima
19.	Lake Vermilion	Danville
20.	C.B. & Q., Reservoir No. 28	Camp Point
21.	Clayton, Reservoir No. 29	Clayton
22.	Mt. Sterling, Reservoir No. 33	Mt. Sterling
23.	Virginia Reservoir	Virginia
24.	Power Farms, Pond No. 43	Cantrall
25.	G. M. & O. Lake, Pond No. 15	Tallula
26.	Holton Farms, Pond No. 38-1	Sherman
27.	Holton Farms, Pond No. 38-2	Sherman
28.	Hose & Davis Farms, Pond No. 45	Pleasant Plains
29.	Aschauer, Pond No. 33	Riverton
30.	Lake Decatur	Decatur
31.	Knapp, Pond No. 29	Springfield
32.	Lake Springfield	Springfield
33.	Jacksonville, Pond No. 24	Jacksonville
34.	Elliot State Bank, Pond No. 25	Jacksonville
35.	Morgan, Pond No. 46	Jacksonville
36.	Mauvaise Terre Lake, Pond No. 21	Jacksonville
37.	Schmidt, Pond No. 44	Chatham
38.	Lake Oakland	Oakland
39.	Big Blue Creek Reservoir	Pittsfield
40.	Pittsfield, Reservoir No. 34	Pittsfield
41.	Franklin, Pond No. 16	Franklin
42.	Langdon, Pond No. 42	Franklin
43.	Waverly, Pond No. 17	Waverly
44.	Roodhouse, Pond No. 4	Roodhouse
45.	Hillview, Pond No. 9	Hillview

TABLE 3. Illinois Lakes with Sediment Data (continued)

	Name of Reservoir	Location
46.	Whitehall, Pond No. 5	Whitehall
47.	Vineyard, Pond No. 10A	Whitehall
48.	Lake Charleston	Charleston
49.	Ridge Lake	Charleston
50.	Craig and Davidson Lake	Martinsville
51.	Stevenson's Lake	Martinsville
52.	Greenfield, Pond No. 8	Greenfield
53.	Woodbine, Pond No. 6	Greenfield
54.	Arctic Lake	Carlinville
55.	Vevay Park Lake	Greenup
56.	Lake Carlinville	Carlinville
57.	Walton Park Lake	Litchfield
58.	Edwards Lake	Gillespie
59.	Lake Gillespie	Gillespie
60.	New Mount Olive Reservoir	White City
61.	Wilsonville, Mine Pond No. 4	Wilsonville
62.	Lake Staunton	Staunton
63.	Panama Lake	Panama
64.	Etcheson's Lake	Vandalia
65.	Patterson Lake	Edgewood
66.	Farina Lake	Farina
67.	Schaefer Lake	Edwardsville
68.	Kinmundy, I.C.R.R. Reservoir	Kinmundy
69.	New Olney Reservoir	Olney
70.	Brown Park Lake	Flora
71.	Salem City Reservoir	Salem
72.	Racoon Lake	Centralia
73.	Steiner Lake	Fairfield
74.	Ashley City Reservoir	Ashley
75.	Nashville Reservoir	Nashville
76.	Bluford, I.C.R.R. Reservoir	Bluford
77.	Farrell Lake	Mt. Vernon
78.	Lake Miller	Mt. Vernon
79.	Mt. Vernon, Reservoir No. 2	Mt. Vernon
80.	Lake Coulterville	Coulterville
81.	Lake Duquoin	Sunfield
82.	Norris City Reservoir	Norris City
83.	Christopher City Reservoir	Christopher
84.	Thompsonville, I.C.R.R. Reservoir	Thompsonville
85.	West Frankfort Reservoir (New)	West Frankfort
86.	Johnson City Reservoir	Johnson City
87.	Herrin, Reservoir No. 1	Herrin
88.	Baker's Lake	Marion
89.	Flucks Lake	Marion
90.	Knights of Pythias Lake	Marion

TABLE 3. Illinois Lakes with Sediment Data (concluded)

Name of Reservoir	Location
91. Marion Reservoir	Marion
92. Eldorado Reservoir	Eldorado
93. Dering Coal Co. Reservoir	Eldorado
94. Carbondale Reservoir	Carbondale
95. Crab Orchard Lake	Carbondale
96. Little Grassy Lake	Carbondale
97. Alto Pass Reservoir	Alto Pass
98. Anna State Hospital Lake	Anna

significantly improve the regional correlations. The regionalization of the lakes was improved by plotting the PCR versus CP/I on log-log graphs by considering various regional configurations. The final regions are shown in figure 4. They do not cover the whole state because in some large areas there were either no lakes or no sediment surveys. The following relations were obtained from the plots:

Region	a	β	Range, $^{CP}/I$
1	0.520	-0.293	0.02 - 0.8
2	0.520	-0.563	0.04 - 0.7
3	0.930	-0.563	0.28 - 0.6
4	0.212	-0.485	0.03 - 0.7
5	0.205	-0.705	0.04 - 1.0
6	0.261	-0.932	0.03 - 0.8
7	0.380	-0.809	0.11 - 0.9
8	0.203	-0.593	0.05 - 0.8
9	0.584	-0.012	0.16 - 0.6

The percent capacity reduction PCR is obtained from

$$PCR = a\ (^{CP}/_{I})^{\beta}$$

in which CP is the average capacity over the period considered. The coefficient a is a function of factors such as sediment characteristics, lake operation, annual precipitation and storm distributions, and overland slopes and general land use. Regionalization assumes minor variations from the mean for these factors over the region under consideration. The extrapolations beyond the range of $(^{CP}/_{I})$ values from the data may be justifiable if the extrapolations are for $(^{CP}/_{I})$ values not too far away from the data values. There were some data points (about 10) which may be considered outliers as far as the above relations are concerned. The reasons for such outliers may be the type of outlet works and method of lake operation, watershed management practices, atypical land use, etc.

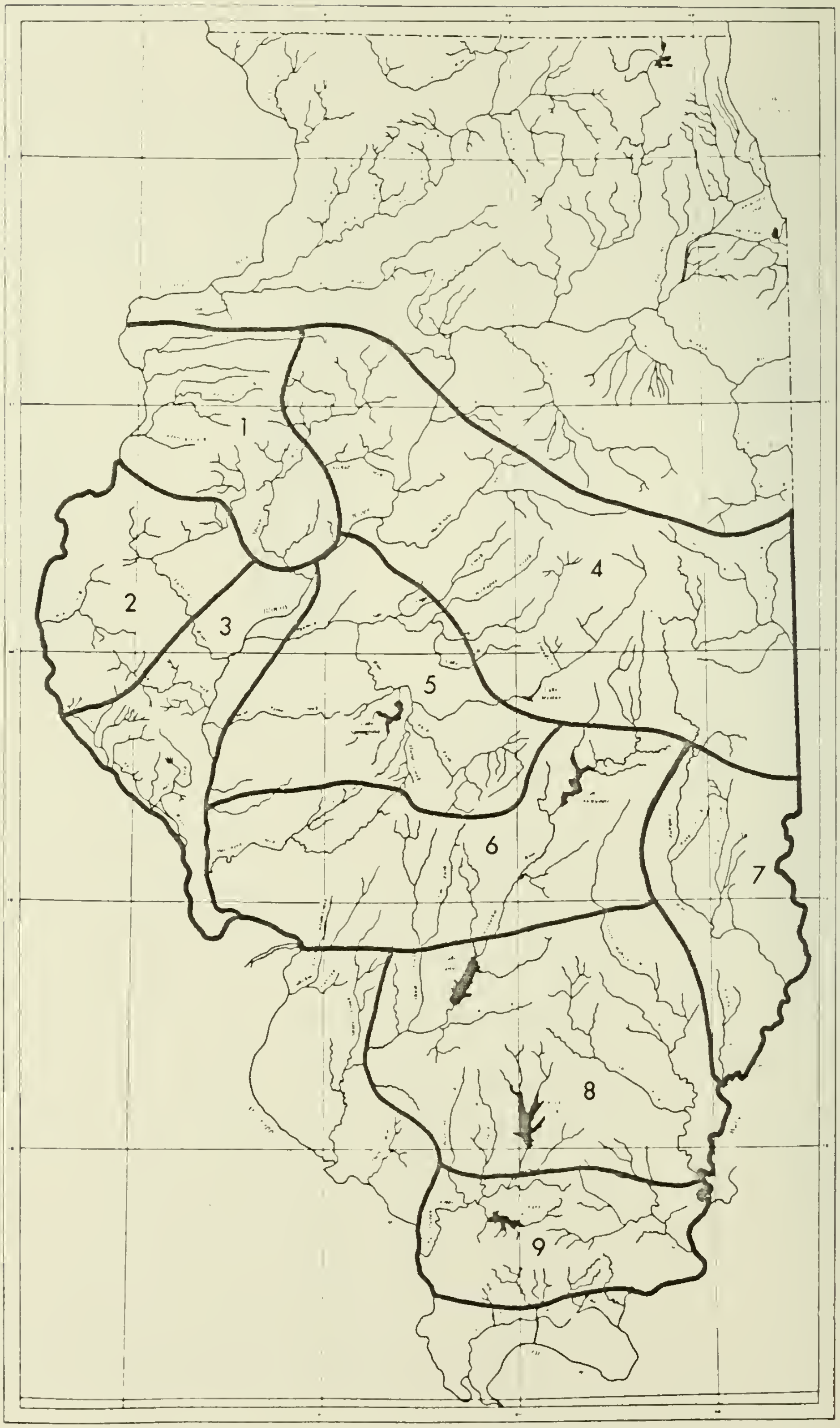


Figure 4. Regionalization of reservoir capacity loss due to sedimentation

A comparison of the methods in Bulletin 51 (Stall, 1964), those in the UMRCBS report (1970) and those developed in this study, in terms of matching the percent capacity reductions of the 98 lakes surveyed, showed that the methods in both the UMRCBS study and this study are significantly superior to those in Bulletin 51, and that the simple regional equations developed in this study yield somewhat better estimates than the UMRCBS methods which involve judgment about the trap efficiency and the specific weight of reservoir sediments.

FISH SUITABILITY CURVES

Instream flow needs arise from various uses such as recreation, fisheries and aquatic habitats, and navigation. The U.S. Fish and Wildlife Service's Cooperative Instream Flow Service Group has been very active in developing methodologies for estimating streamflows suitable for maintenance of fisheries. Research being conducted by them and by others has helped in a continuing improvement in the understanding of the problem and in its solution.

The suitability of a stream reach in maintaining fish habitats depends on a number of factors such as flow velocity, depth and width of stream, water quality, temperature, and stream bottom materials. In this study, only two important parameters are considered, both of which can be changed through management of flows: flow velocity, V, and flow depth, D.

Suitability Curves for Nine Target Species

The Illinois Environmental Protection Agency provided fish suitability or preference tables for the following juvenile and adult fish: bluegill, bluntnose, carp, channel catfish, largemouth bass, smallmouth bass, drum, white bass, and white crappie. These 9 fish are the target species for studies relating to Illinois streams. The fish suitability or preference as a function of flow velocity and depth for each of the 9 fish, juvenile and adult, are given in table 4. Analyses can include the habitat preferences of each life stage such as spawn, fry, juvenile, and adult. However, only the preferences for the juvenile and adult fish are analyzed in this study to estimate the effect of various low flow releases from impounding reservoirs on the fish population.

The fish suitability or preference curves are drawn in figure 5 for the 9 target fish, juvenile and adult, with respect to flow velocity, V, and flow

TABLE 4 Fish Preferences for Various Velocities and Depths of Flow

1. BLUEGILL

JUVENILE				ADULT			
VEL	PREF	DEPTH	PREF	VEL	PREF	DEPTH	PREF
0.00	1.00	0.00	0.00	0.00	1.00	0.00	0.00
.04	1.00	.50	0.00	.22	1.00	.80	0.00
.06	.98	.65	.04	.26	.94	1.05	.01
.08	.95	.78	.10	.32	.84	1.26	.03
.10	.86	.98	.24	.43	.58	1.52	.07
.15	.56	1.12	.36	.51	.44	1.80	.13
.20	.32	1.22	.48	.58	.34	2.10	.21
.23	.26	1.30	.58	.63	.28	2.30	.30
.25	.20	1.38	.74	.70	.21	2.54	.43
.29	.13	1.42	.83	.77	.16	2.75	.60
.33	.09	1.50	.90	.84	.13	3.00	.80
.38	.05	1.60	.96	.92	.11	3.23	.91
.43	.02	1.64	.99	1.32	.03	3.40	.98
.48	0.00	1.70	1.00	1.47	.01	3.50	1.00
100.00	0.00	3.45	1.00	1.52	0.00	4.50	1.00
		3.53	.99	100.00	0.00	4.60	.99
		3.80	.91			4.82	.95
		4.12	.80			5.20	.85
		4.44	.66			5.40	.78
		4.85	.46			5.70	.68
		5.20	.32			6.13	.50
		5.40	.24			6.70	.30
		5.70	.16			7.08	.19
		6.00	.10			7.35	.12
		6.20	.06			7.60	.07
		6.40	.04			7.80	.03
		6.60	.02			8.00	0.00
		6.90	0.00			100.00	0.00
		100.00	0.00				

TABLE 4. Continued

2. BLUNTNOSE

JUVENILE				ADULT			
VEL	PREF	DEPTH	PREF	VEL	PREF	DEPTH	PREF
0.00	1.00	0.00	0.00	0.00	1.00	0.00	0.00
.11	1.00	.30	0.00	.12	.93	.19	0.00
.25	.89	.42	.31	.19	.80	.38	.48
.31	.78	.46	.50	.21	.60	.41	.80
.44	.20	.61	1.00	.25	.39	.50	1.00
.50	.11	.70	1.00	.31	.30	.83	1.00
.63	.04	.78	.90	.50	.19	1.00	.88
1.00	0.00	.83	.75	.75	.10	1.04	.80
100.00	0.00	.84	.40	1.16	.03	1.06	.50
		.86	.30	1.34	0.00	1.16	.31
		1.00	.18	100.00	0.00	1.38	.15
		1.50	0.00			1.75	.05
		100.00	0.00			2.30	.01
						2.80	0.00
						100.00	0.00

3. CARP

JUVENILE				ADULT			
VEL	PREF	DEPTH	PREF	VEL	PREF	DEPTH	PREF
0.00	1.00	0.00	0.00	0.00	1.00	0.00	0.00
.25	1.00	1.90	0.00	.25	1.00	1.40	0.00
.35	.98	2.10	.02	.35	.97	1.80	.03
.45	.94	2.40	.06	.45	.92	2.00	.06
.52	.88	2.60	.12	.50	.86	2.25	.10
.55	.80	2.80	.22	.55	.46	2.50	.16
.56	.41	3.00	.84	.62	.42	2.75	.24
.65	.35	3.10	.92	.75	.38	2.90	.34
.80	.30	3.30	.97	.95	.36	3.00	.48
1.00	.26	3.60	1.00	1.90	.33	3.20	.90
1.20	.25	6.00	1.00	2.30	.32	3.30	.96
2.60	.24	6.20	.98	2.60	.29	3.40	.98
2.90	.22	6.40	.92	2.83	.26	3.60	1.00
3.40	.17	6.50	.88	3.55	.14	5.90	1.00
4.00	.08	6.60	.36	4.20	.06	6.10	.98
4.40	.04	6.80	.28	4.70	.01	6.20	.96
4.85	0.00	7.00	.24	4.90	0.00	6.35	.90
100.00	0.00	7.60	.18	100.00	0.00	6.65	.70
		8.60	.10			7.10	.40
		9.60	.05			7.30	.32
		10.40	.01			7.85	.22
		11.10	0.00			8.60	.12
		100.00	0.00			9.00	.08
						9.60	.04
						10.20	.01
						10.80	0.00
						100.00	0.00

TABLE 4. Continued

4. CHANNEL CATFISH

JUVENILE				ADULT			
VEL	PREF	DEPTH	PREF	VEL	PREF	DEPTH	PREF
0.00	.07	0.00	0.00	0.00	1.00	0.00	0.00
.75	.10	1.00	0.00	.25	1.00	1.80	0.00
.93	.14	2.40	.46	.30	.98	1.90	.04
1.08	.20	3.40	.66	.35	.96	2.20	.10
1.37	.36	3.60	.72	.75	.84	2.80	.16
1.71	.60	3.80	.80	2.15	.50	3.20	.20
2.05	.92	4.00	.94	2.30	.44	3.40	.24
2.10	.96	4.20	.98	2.40	.38	3.60	.30
2.17	1.00	4.36	1.00	2.52	.32	4.00	.70
3.10	1.00	4.60	.99	2.65	.28	4.20	.82
3.12	.99	4.85	.96	3.35	.20	4.60	.96
3.15	.98	5.00	.90	3.70	.14	4.68	.98
3.25	.74	5.40	.66	4.10	.06	4.80	1.00
3.30	.56	6.20	.41	4.28	0.00	100.00	1.00
3.40	.45	6.80	.30	100.00	0.00		
3.55	.38	9.60	.10				
4.05	.33	12.00	0.00				
4.20	.30	100.00	0.00				
4.35	.24						
4.50	.12						
4.60	0.00						
100.00	0.00						

5. LARGEMOUTH BASS

JUVENILE				ADULT			
VEL	PREF	DEPTH	PREF	VEL	PREF	DEPTH	PREF
0.00	1.00	0.00	0.00	0.00	1.00	0.00	0.00
.15	.99	.20	0.00	.20	1.00	1.00	0.00
.25	.96	.57	.12	.25	.98	1.60	.04
.35	.90	.80	.26	.37	.91	2.36	.12
.55	.70	.95	.38	.50	.83	3.41	.30
.75	.44	1.02	.48	.68	.68	3.90	.40
.90	.30	1.15	.80	.90	.42	4.70	.60
1.05	.22	1.28	.92	1.10	.32	5.43	.82
1.32	.11	1.38	.98	1.28	.24	5.70	.90
1.60	.04	1.48	1.00	1.45	.20	5.95	.96
1.77	.01	100.00	1.00	1.90	.14	6.20	.99
2.00	0.00			2.25	.08	7.00	1.00
100.00	0.00			2.55	0.00	9.00	1.00
				100.00	0.00	20.00	0.00
						100.00	0.00

TABLE 4. Continued

6. SMALLMOUTH BASS

JUVENILE				ADULT			
VEL	PREF	DEPTH	PREF	VEL	PREF	DEPTH	PREF
0.00	1.00	0.00	0.00	0.00	.73	0.00	0.00
.28	1.00	.13	0.00	.35	.76	1.00	0.00
.35	.96	.50	.14	.65	.84	1.50	.07
.45	.87	.70	.26	.90	.93	2.00	.20
.55	.74	1.00	.51	1.45	1.00	2.72	.46
.60	.64	1.13	.74	1.60	1.00	3.25	.70
.75	.49	1.20	.95	1.80	.97	3.48	.82
1.02	.28	1.30	1.00	1.90	.95	3.70	.92
1.17	.20	100.00	1.00	2.10	.90	3.90	.98
1.40	.12			2.20	.81	4.05	1.00
1.70	.06			2.28	.76	100.00	1.00
2.00	0.00			2.30	.62		
100.00	0.00			2.40	.46		
				2.55	.30		
				2.75	.16		
				2.90	.08		
				3.15	.04		
				3.25	0.00		
				100.00	0.00		

7. DRUM

JUVENILE				ADULT			
VEL	PREF	DEPTH	PREF	VEL	PREF	DEPTH	PREF
0.00	1.00	0.00	0.00	0.00	1.00	0.00	0.00
.25	1.00	1.82	0.00	.45	1.00	2.73	0.00
.52	.96	2.13	.21	.58	.99	2.80	.12
.75	.90	2.60	.60	.67	.95	2.95	.60
.95	.84	2.82	.74	1.00	.90	3.06	.76
1.30	.72	3.10	.87	1.35	.80	3.20	.86
1.90	.46	3.38	.96	1.75	.65	3.33	.94
2.36	.29	3.57	1.00	2.33	.41	3.45	.98
2.67	.20	9.00	1.00	2.64	.30	3.54	1.00
2.75	.18	100.00	1.00	2.76	.26	9.00	1.00
3.65	.10			3.35	.14	100.00	1.00
4.20	.04			3.67	.06		
4.50	0.00			3.88	0.00		
100.00	0.00			100.00	0.00		

TABLE 4. Concluded

8. WHITE BASS

JUVENILE				ADULT			
VEL	PREF	DEPTH	PREF	VEL	PREF	DEPTH	PREF
0.00	1.00	0.00	0.00	0.00	1.00	0.00	0.00
2.00	1.00	1.40	0.00	2.00	1.00	2.95	0.00
2.07	.98	1.90	.24	2.25	.93	3.60	.28
2.35	.88	2.40	.56	2.47	.84	4.20	.58
2.65	.74	2.70	.70	2.70	.73	4.60	.72
2.95	.56	3.20	.85	3.05	.52	5.00	.84
3.50	.24	3.60	.94	3.45	.26	5.50	.94
3.85	.06	3.90	.98	3.70	.12	5.80	.98
4.00	0.00	4.10	1.00	3.85	.06	6.00	1.00
100.00	0.00	7.90	1.00	4.00	0.00	18.00	1.00
		8.30	.97	100.00	0.00	100.00	1.00
		9.30	.86				
		10.00	.75				
		10.80	.61				
		12.60	.24				
		13.60	.06				
		14.00	0.00				
		100.00	0.00				

9. WHITE CRAPPIE

JUVENILE				ADULT			
VEL	PREF	DEPTH	PREF	VEL	PREF	DEPTH	PREF
0.00	1.00	0.00	0.00	0.00	1.00	0.00	0.00
.25	1.00	.72	0.00	.25	1.00	2.00	0.00
.50	.94	1.00	.54	.33	.96	2.40	.10
.80	.84	1.10	.68	.45	.84	2.60	.20
1.05	.74	1.30	.84	.55	.70	2.75	.32
1.45	.54	1.50	.94	.65	.45	3.00	.64
1.82	.38	1.60	.98	.75	.34	3.20	.78
2.00	.32	1.70	1.00	.85	.26	3.53	.94
2.30	.24	3.72	1.00	.99	.20	3.75	1.00
2.68	.16	3.95	.96	1.13	.16	100.00	1.00
2.94	.12	4.30	.86	1.62	.10		
3.50	.06	4.70	.72	2.55	.04		
3.90	0.00	5.20	.54	3.05	0.00		
100.00	0.00	6.00	.35	100.00	0.00		
		7.10	.12				
		7.60	0.00				
		100.00	0.00				

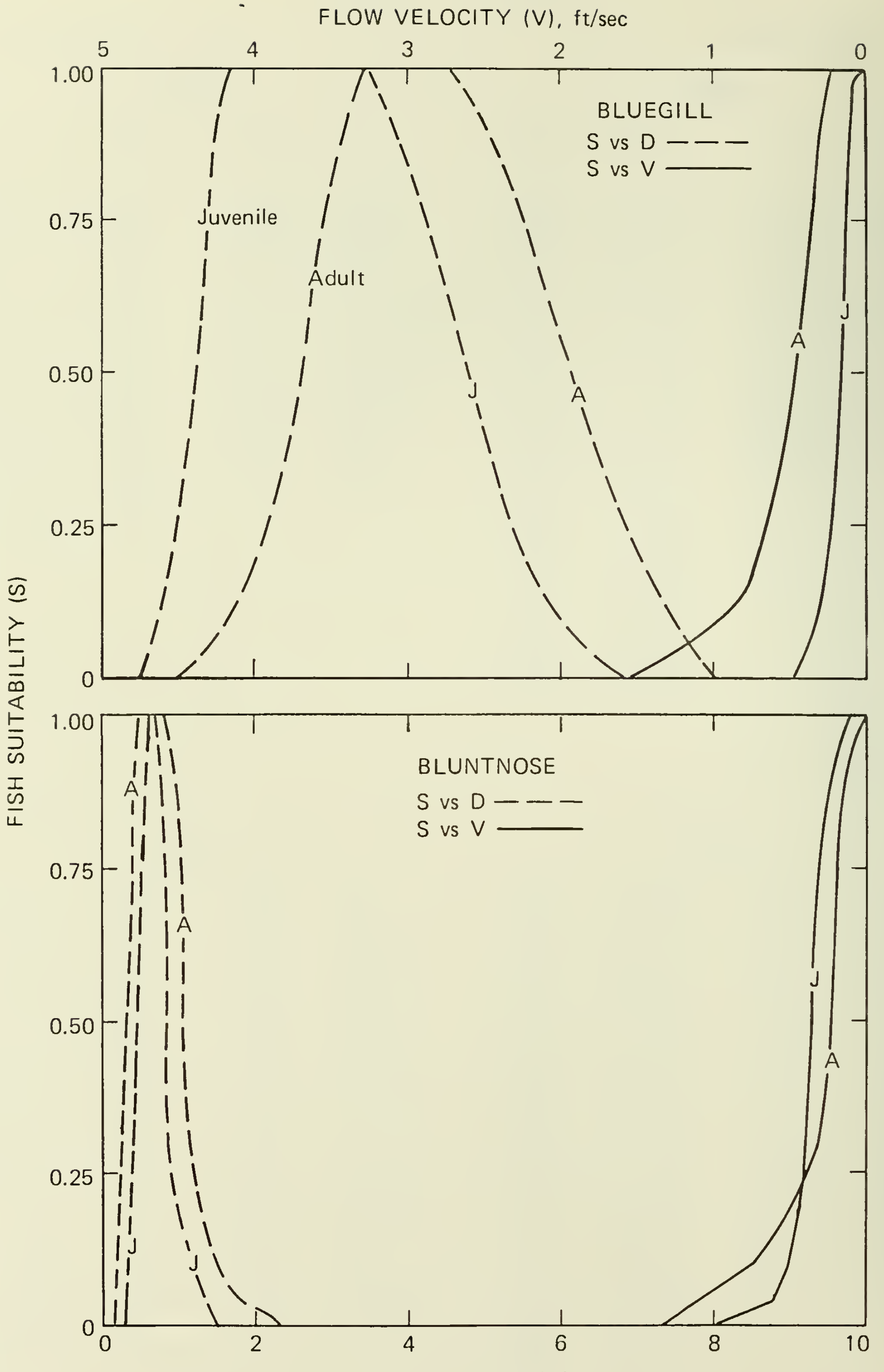


Figure 5. Fish suitability or preference curves

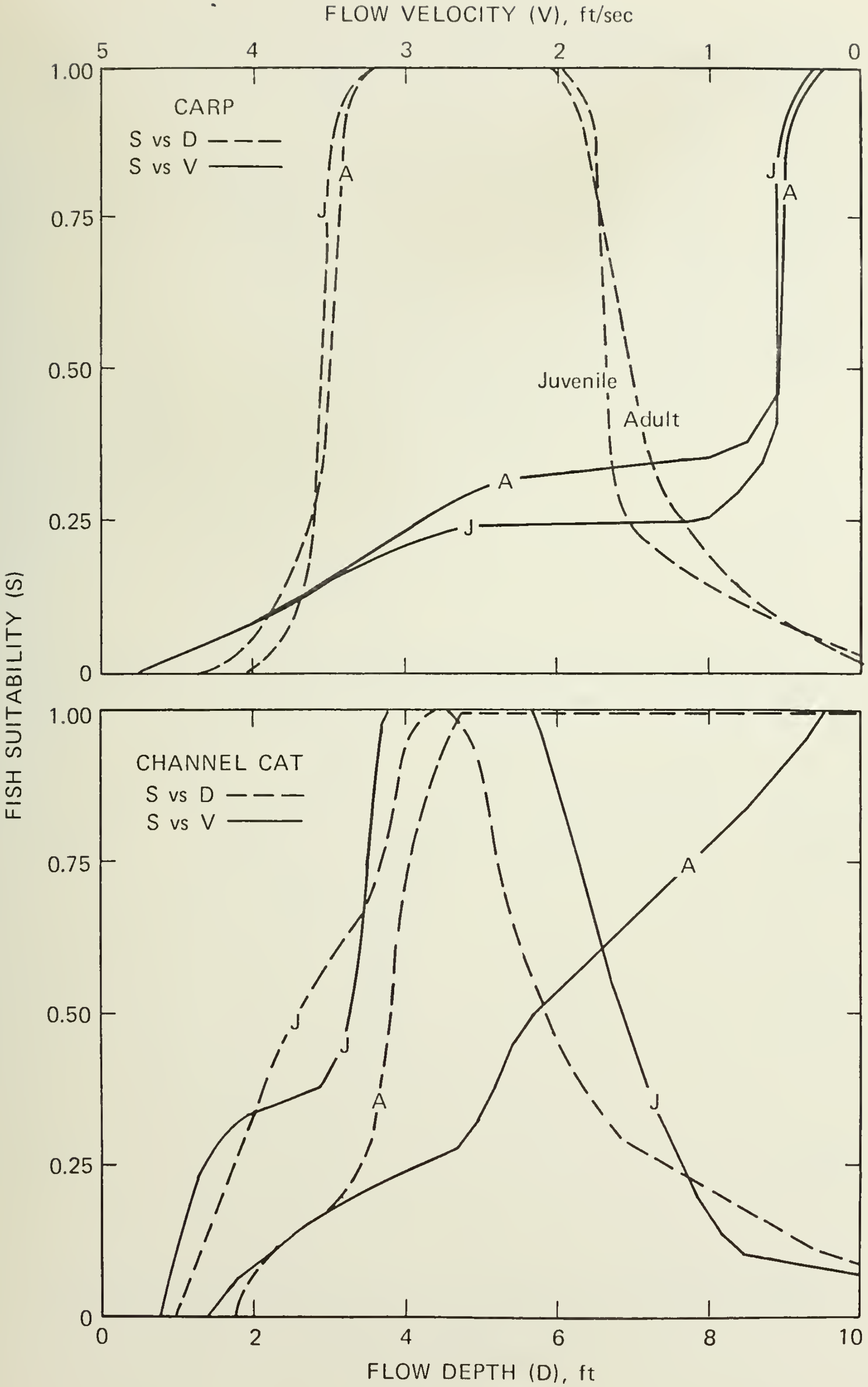


Figure 5. Continued

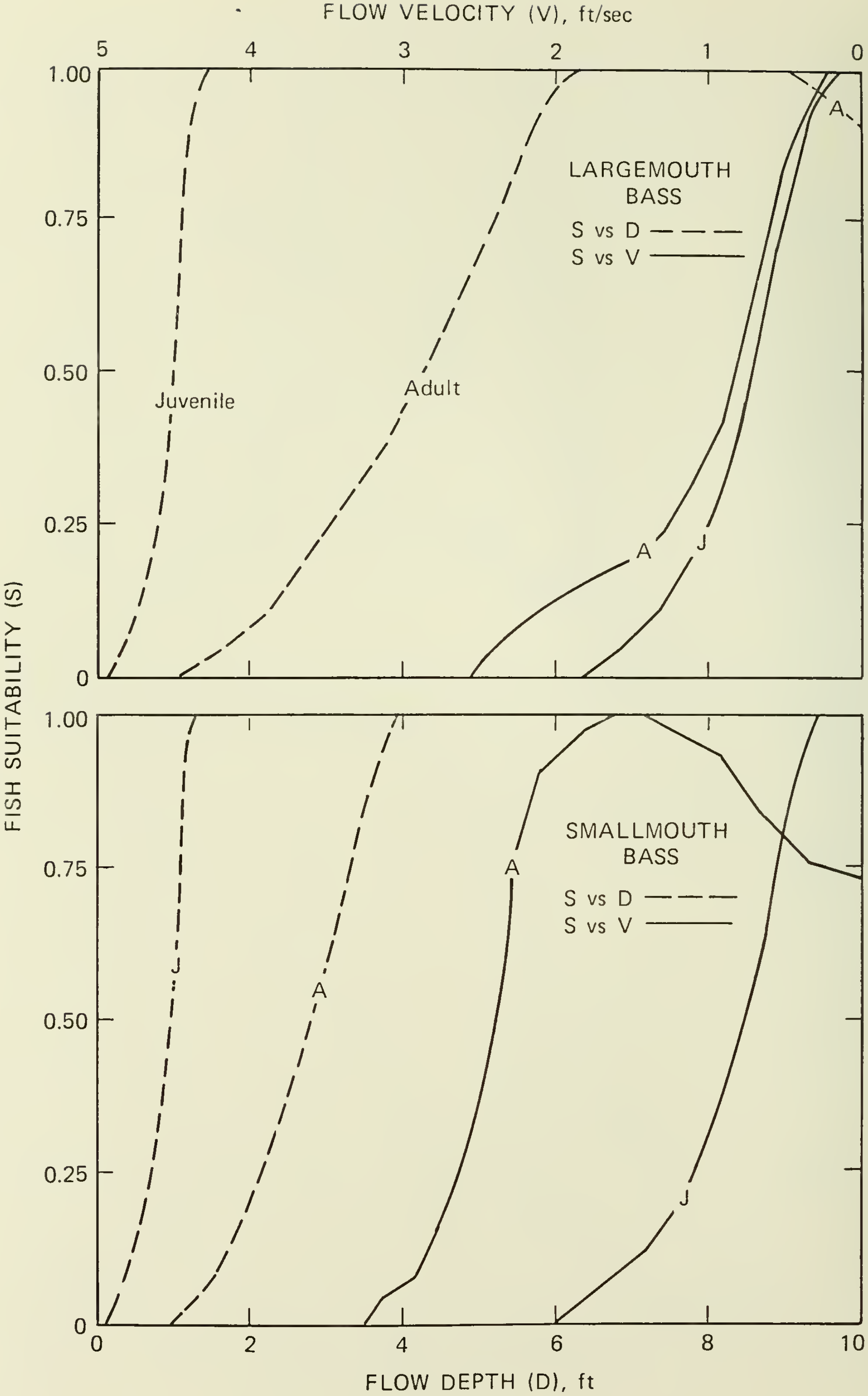


Figure 5. Continued

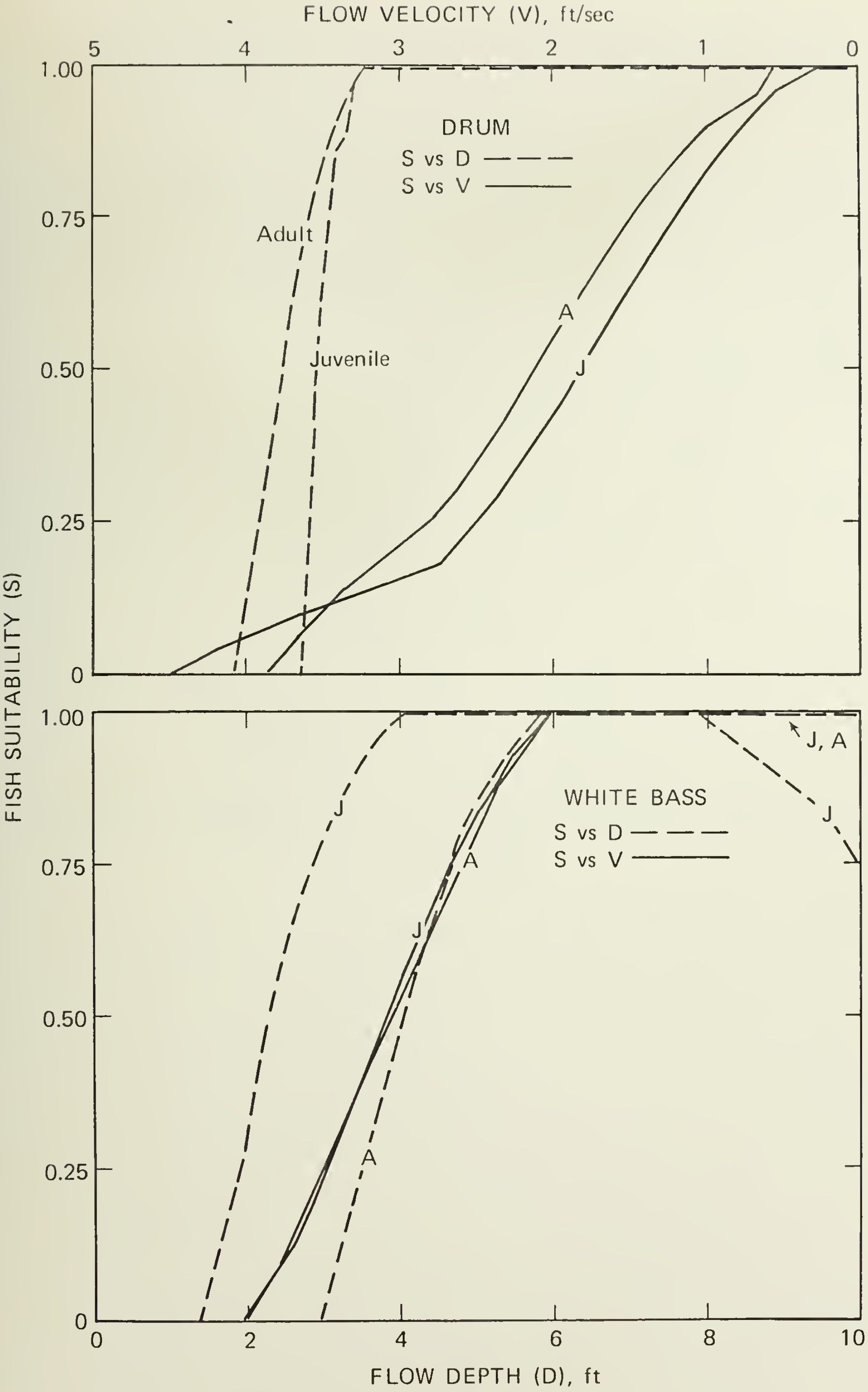


Figure 5. Continued

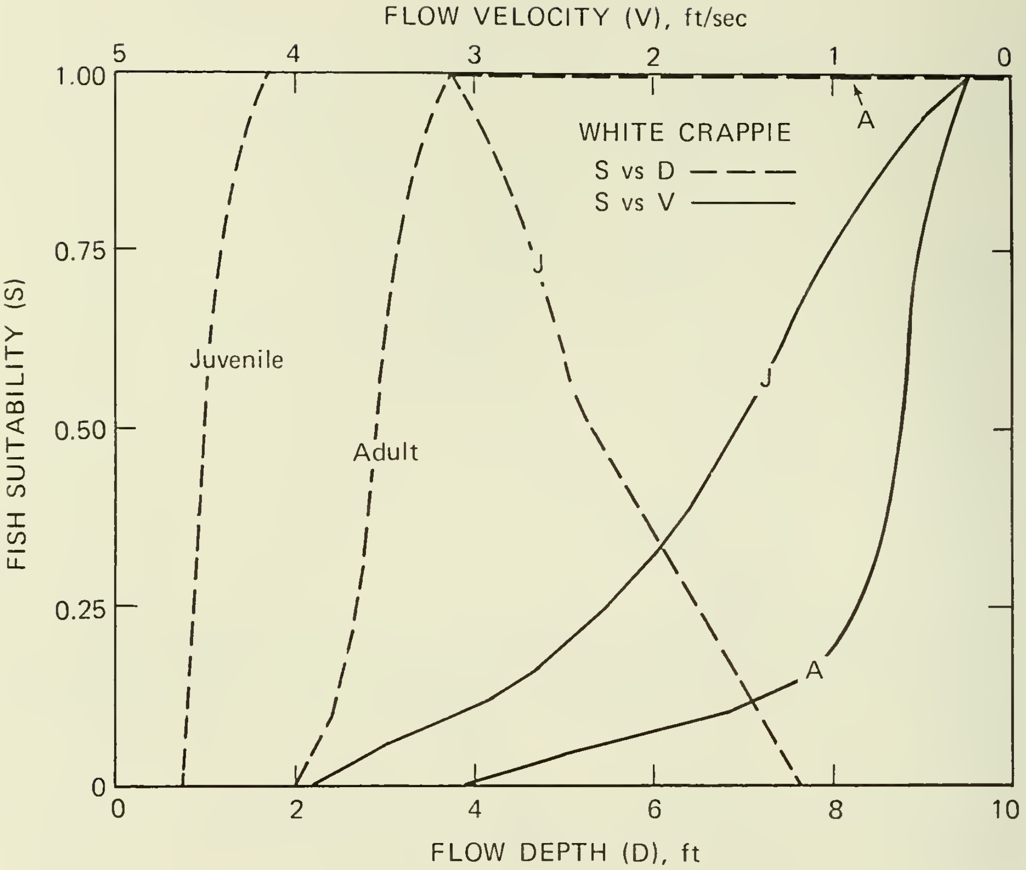


Figure 5. Concluded

depth, D. Some observations of interest for suitability $\geq$ 0.5 are:

1) Bluegill. The juvenile fish prefers a dpeth of 1.2 - 4.8 ft and a velocity $\leq$ 0.16 ft/sec, whereas the adult prefers a depth of 2.6 - 6.1 ft and a velocity $\leq$ 0.48 ft/sec. The overall preference is for very low to low velocities and low to medium depths---a condition in pools at low to medium flows.

2) Bluntnose. The juvenile fish prefers a depth of 0.5 - 0.8 ft and a velocity $\leq$ 0.37 ft/sec, whereas the adult perfers a depth of 0.4 - 1.1 ft and a velocity $\leq$ 0.23 ft/sec. The overall preference is for very low to low velocities and very low to low depths---a condition at riffles and shallow parts of the pools at very low to low flows.

3) Carp. The juvenile fish prefers a depth of 2.9 - 6.6 ft and a velocity $\leq$ 0.56 ft/sec, whereas the adult likes a depth of 3.0 - 7.0 ft and a velocity $\leq$ 0.51 ft/sec. The overall preference is for very low to low velocities and medium to high depths---a condition in deep pools at low and medium flows.

4) Channel Cat. The juvenile fish prefers a depth of 2.5 - 5.9 ft and a velocity of 1.57 - 3.35 ft/sec, whereas the adult fish likes a depth of 3.8 and higher and a velocity $\leq$ 2.15 ft/sec. The overall preference is for 3 - 6 ft depth and 1.5 - 2.2 ft/sec velocity---a condition of medium flow in the pools and somewhat higher flows at the riffles.

5) Largemouth Bass. The juvenile fish prefers a depth $\geq$ 1.0 ft and a velocity $\leq$ 0.70 ft/sec, whereas the adult fish prefers a depth $\geq$ 4.3 ft and a velocity $\leq$ 0.83 ft/sec. The overall preference is for medium to high depths and low velocities---a condition of medium flows in the pools.

6) Smallmouth Bass. The juvenile fish prefers a depth $\geq$ 1.0 ft and a velocity $\leq$ 0.74 ft/sec, whereas the adult fish likes a depth $\geq$ 2.8 ft and a

velocity $\leq$ 2.62 ft/sec. The overall preference is for low to high velocities and depths and this fish may be found at different ranges of flow.

7) Drum. The juvenile fish prefers a depth $\geq$ 2.5 ft and a velocity $\leq$ 1.81 ft/sec, whereas the adult prefers a depth $\geq$ 2.9 ft and a velocity $\leq$ 2.12 ft/sec. The overall preference is for depths $\geq$ 2.5 ft and a velocity $\leq$ 1.8 ft/sec---a condition which may be found at riffles and pools at medium and higher flows.

8) White Bass. The juvenile fish prefers a depth of 2.3 - 11.3 ft and a velocity $\leq$ 3.05 ft/sec, whereas the adult likes a depth $\geq$ 4.0 ft and a velocity $\leq$ 3.08 ft/sec. The overall preference is for depth $\geq$ 3 ft and velocity $\leq$ 3 ft/sec---a condition which may be found in the pools at low to high flows and at the riffles at medium to high flows.

9) White Crappie. The juvenile fish prefers a depth of 1.0 - 5.4 ft and a velocity $\leq$ 1.54 ft/sec, whereas the adult prefers a depth $\geq$ 2.9 ft and a velocity $\leq$ 0.63 ft/sec. The overall preference is for low to medium velocities and low to high depths---such conditions can occur in pools and at riffles for low to high flows.

The domain for 0.5 - 1.0 suitability is mapped in terms of velocity and depth for the juvenile fish in figure 6 and for the adult fish in figure 7 for all the target species. It is evident from figure 6 that all the juvenile fish except for bluntnose and channel catfish have some common V-D space. Similarly, figure 7 shows that with the exception of bluntnose fish, the adult fish have some common V-D space.

Riffles and Pools

Let the riffles have an average length l_r along the stream and an average width w_r for a certain flow in a stream reach. The corresponding average pool

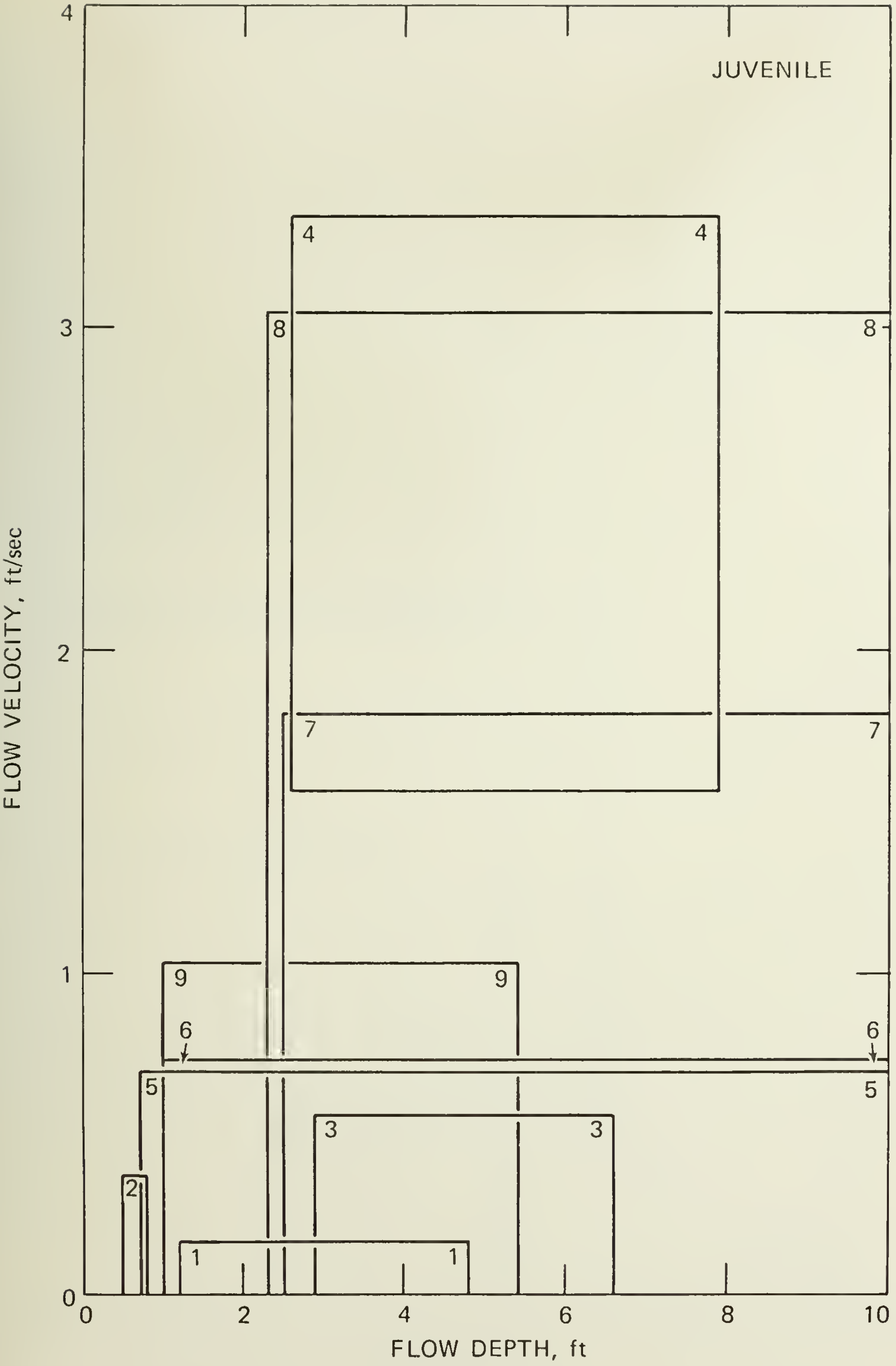


Figure 6. Velocity-depth domain for juvenile fish preference 0.5 - 1.0

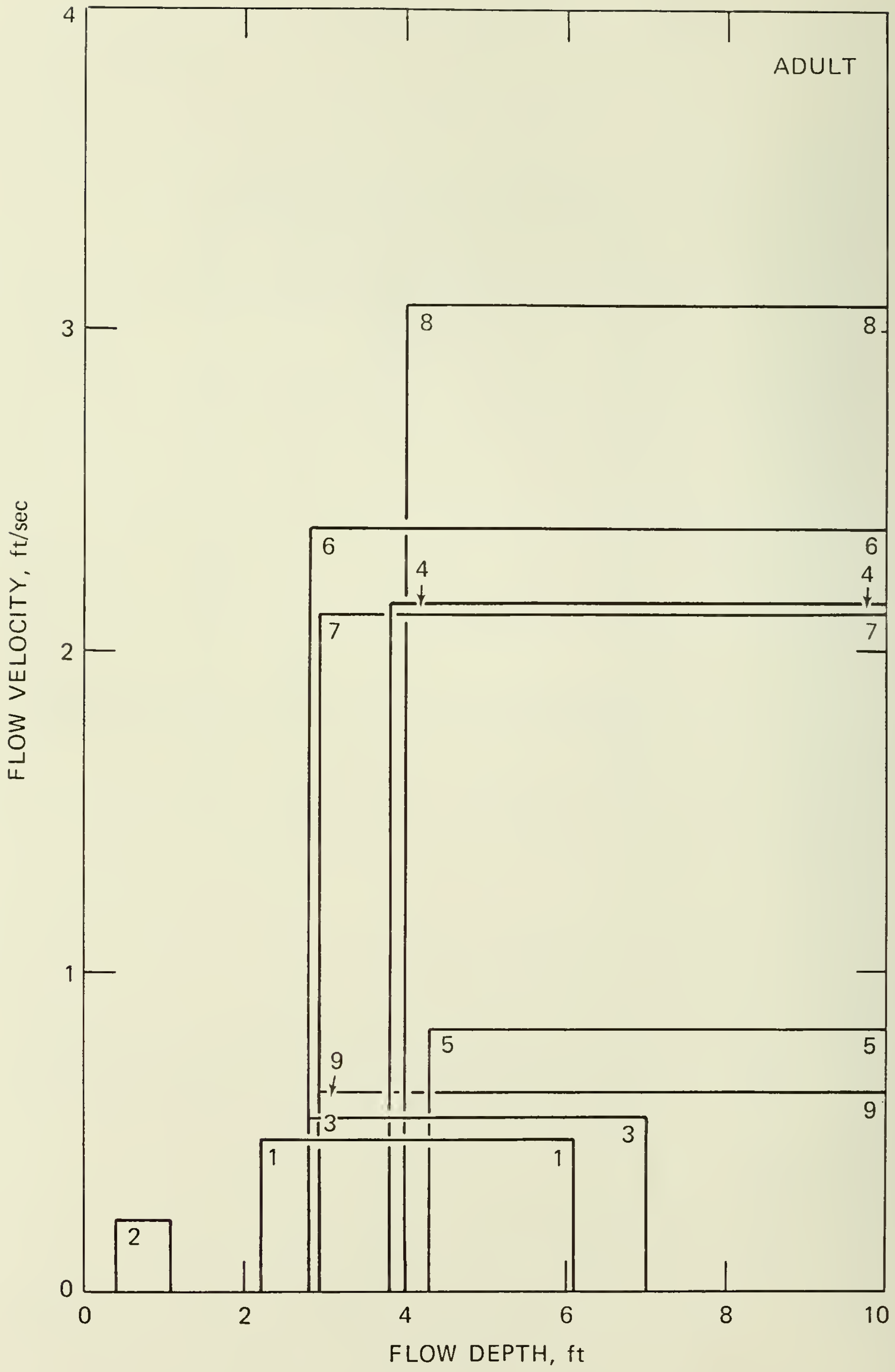


Figure 7. Velocity-depth domain for adult fish preference 0.5 - 1.0

lengh and width are denoted by l_p and w_p, respectively. The average depths for the riffle and pool are d_r and d_p. The local values of d_r and d_p vary from the average values for the riffle and pool, and the percent variation of the local values from the average value is usually less for the riffles than the pools. The hydraulic geometry relations yield the average values of depth and velocity. The local values in the riffles and pools may be higher or lower than the average values. It is common knowledge that the velocity and depth at the banks are much lower than the average values for a straight river reach. However, these values may be higher along one bank along the bend. The varying velocities and depths in riffles and pools provide a range of subareas or cells of water more suitable to one fish than the other, depending on their relative preferences. This variety helps in maintaining different life stages of various fishes and provides a semblance of continuum for their development, even with more frequent flow variations.

The IFG Incremental Methodology

The Cooperative Instream Flow Service Group of the U.S. Fish and Wildlife Service has developed a methodology (Bovee and Milhous, 1978), termed the IFG Incremental Methodology, to describe the effects of incremental changes in streamflow on the instream fishery potential. The methodology allows calculations of weighted usable area, WUA, as an index of habitat suitability. The WUA in a river reach divided into n cells is defined as

$$WUA = \sum_{i=1}^{n} S(d_i) \times S\,(v_i) \times \ldots\ldots\ldots\ldots \times A_i$$

in which S(d), S(v), ..., are suitability indexes for depth, velocity, ...; A is the surface area of the cell which is relatively homogeneous in respect to d, v, ...; and subscript i refers to the cell i. This procedure approximates the total water surface area in a simulated reach to an equivalent area of preferred habitat for the fish under consideration.

The concept of multiplying the suitability indexes or preferences is rather open to question. The preference curves for velocity and depth are derived, considering both velocity and depth as independent variables. However, the hydraulic geometry relations indicate a definite relationship between velocity and depth in terms of drainage area and percent flow duration. Consider the case for a low-flow release that gives $S(d) = 0.4$ and $S\ (v) = 0.4$ for a particular fish. The multiplication concept will yield a combined suitability or preference of 0.16. Two other criteria can be considered: the minimum (MIN) of the two preferences, and the geometric mean (GM) of the two preferences. Then:

$$\text{MPL preference} = 0.4 \times 0.4 = 0.16$$

$$\text{MIN preference} = \min\ [0.4,\ 0.4] = 0.4$$

$$\text{GM preference} = \sqrt{0.4 \times 0.4} = 0.4$$

When the two preferences are equal, both MIN and GM criteria represent the habitat suitability condition but the MPL (multiplication) preference grossly underestimates it. For a case with unequal preferences, say 0.3 and 0.7, the three criteria yield the following:

$$\text{MPL preference} = 0.3 \times 0.7 = 0.21$$

$$\text{MIN preference} = \min\ [0.3,\ 0.7] = 0.3$$

$$\text{GM preference} = \sqrt{0.3 \times 0.7} = 0.46$$

The GM preference implies that the combined reference will be less than the mean preference but more than the MIN preference because of the positive effect of the higher preference. GM preference or the MIN preference should give a habitat suitability index closer to the actual than the MPL. The GM or the mean of GM and MIN preferences may be the desirable habitat suitability index for use in WUA computations.

METHODOLOGY AND COMPUTER PROGRAM

The fish suitability or preference is evaluated with MIN and GM criteria for both juveniles and adults of 9 target fish, for both riffle and pool conditions, and for each of the 8 low flow release criteria below each of the 123 stream gaging stations. The reservoir costs for developing a net supply equal to 2, 5, 10, and 20 percent of mean streamflow and a design drought recurrence interval of 25 or 40 years are computed with 10 low flow release criteria: no mandatory low flow release, a low flow release equal to $0_{7,\ 10}$ to be met once in 10 years, and 8 low flow releases, C1 through C8, to be met at 5-, 10-, 20-, 25- or 40-year recurrence intervals. The reservoir cost depends on the storage capacity. Evaluation of storage for meeting the design supply and the low flow release involves consideration of lake evaporation and sedimentation. A brief description of the data inputs and salient features of the computer program, developed to yield needed information, follows together with an explanation of methodology where necessary.

Data Inputs

The main data inputs are fish suitability or preference, flow velocity and depth for the 8 low flow releases, supply-storage-drought duration-frequency (or recurrence interval) information, net lake evaporation data, and lake sedimentation data.

Fish Suitability or Preference

The data on fish preferences (both juvenile and adult) for the 9 target fish as contained in table 4 are stored in the computer for use in the program.

Flow Velocity and Depth for Low Flow Releases

The data on 8 low flow releases, in cfs, and associated flow velocity and depth (in ft/sec and ft, respectively) as given in table 2 for each of the 123 stations are stored in the computer.

Supply-Storage-Drought Duration-Frequency

The net reservoir storage, in inches, and the associated drought duration for critical reservoir drawdown, in months, for 11 supply rates equal to 2, 5, 10, 15, 20, 25, 30, 35, 40, 45, and 50 percent of mean flow and 5 recurrence intervals (5, 10, 20, 25, and 40 years) are stored in the computer for 112 gaging stations. Necessary data on these stations were available from Bulletins 51 (Stall, 1964) and 51A (Terstriep et al., in preparation, 1981). A typical example of such data is shown below:

KICKAPOO CREEK NEAR LINCOLN

1	0.00	.03	.14	.29	.47	.68	.91	1.16	1.40	1.65	1.93
1	1	2	4	5	6	6	7	7	7	7	8
2	0.00	.05	.20	.39	.62	.87	1.12	1.40	1.69	2.00	2.32
2	1	4	5	6	7	7	8	8	8	9	9
3	.01	.08	.25	.48	.73	1.01	1.31	1.62	1.94	2.28	2.84
3	2	4	6	7	7	8	9	9	9	10	18
4	.01	.08	.27	.51	.77	1.05	1.36	1.68	2.01	2.53	3.16
4	2	4	6	7	8	8	9	9	10	18	18
5	.01	.10	.30	.55	.83	1.14	1.45	1.80	2.43	3.06	3.77
5	2	5	7	7	8	9	9	18	18	18	20

Numbers 1, 2, 3, 4, and 5 refer to 5-, 10-, 20-, 25-, and 40-year recurrence intervals. The eleven columns correspond to supply rates of 2, 5, 10, 15, 20, 25, 30, 35, 40, 45, and 50 percent of mean flow. The first line for each number denotes the net storage in inches to meet a particular demand, and the second line denotes the associated drought duration in months.

Net Lake Evaporation

Net lake evaporation data for 10 locations -- Chicago, Rockford, Moline, Peoria, Springfield, Urbana, and Carbondale in Illinois; St. Louis in Missouri; and Evansville and Indianapolis in Indiana -- were stored in the computer. The data were developed for Bulletin 51A (Terstriep et al., 1981) for 36 critical drought durations -- 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30, 32, 34, 36, 38, 40, 42, 44, 46, 48, 50, 52, 54, 56, 58, and 60 months -- for each of the 5 drought recurrence intervals of 5, 10, 20, 25, and 40 years.

Lake Sedimentation

The values of a and β in the relation

$$PCR = a(^{CP}/_{I})^{\beta}$$

in which PCR is the percent capacity reduction and $^{CP}/_{I}$ is the capacity-inflow ratio, were stored in the computer for the 9 regions.

Reference Data

The serial number (1 to 123), USGS gaging station number, applicable net lake evaporation station number (1 through 10), applicable sediment region (1 through 9), mean monthly flow in inches from Bulletins 51 (Stall, 1964) and 51A (Terstriep et al., in preparation, 1981), and drainage area in square miles at each of the 123 gaging stations were stored in a tabular format in the computer.

For sedimentation purposes, the part of northern Illinois not included in any sediment region (because no lake sediment data are available in that area) is considered to have the same characteristics as region 4; the area west of region 8 is given the same characteristics as region 8; and that below region 9 is taken to have characteristics similar to region 9.

Reservoir Costs Program

A computer program was developed to determine the gross storage (i.e., net storage for meeting water demand and storage needed to meet lake evaporation and sedimentation requirements) for four supply rates of 2, 5, 10 and 20 percent of mean flow, two design recurrence intervals of 25 and 40 years for supply, five recurrence intervals of 5, 10, 20, 25 or 40 years for low flow releases, and eight low flow releases, together with zero and $Q_{7,10}$ flow releases, at each of the 112 gaging stations. The gross storage was converted to the reservoir cost with a suitable cost equation. The program has five main subroutines which are described briefly.

Storage Subroutine

First, the net storage for the four supply rates of 2, 5, 10, and 20 percent of mean flow and the associated drought durations in months is obtained from the supply-storage-drought duration-frequency table (abbreviated as SSDF) for the design recurrence intervals of 25 and 40 years and without any mandatory low flow release. Then, the four supply rates are converted to 9 × 4 matrix, by addition to each of them the low flow releases C1 through C8 and $Q_{7,10}$. The net reservoir storage and the associated drought duration for each of the supply-plus-release rates (total of 36 or 9 × 4) and for recurrence intervals of 5, 10, 20, and 25 years with a supply design drought of 25 years, and for recurrence intervals of 5, 10, 20, and 40 years with supply design drought of 40 years, are obtained by interpolation from the SSDF table. Thus, at each station there are 148 values each of storage and drought duration for each supply design drought of 25 and 40 years; information is stored in two 2 × 148 arrays for storage in inches, ST(2, 148), and drought duration in months, DD (2, 148).

EVAP Subroutine

For a gaging station, the applicable net lake evaporation station is obtained from the reference table. The net lake evaporation, in inches, for the 2 × 148 array for the drought duration in months is obtained from the net evaporation table directly or by interpolation. This table is stored in a matrix form 36 × 5 × 10 in which 36 denotes durations from 1 to 60 months; 5 refers to recurrence intervals of 5, 10, 20, 25 and 40 years; and 10 pertains to the net lake evaporation station. The information on evaporation in inches is stored in EV(2, 148).

SDEVST Subroutine

This (sediment-evaporation-storage) subroutine is used for computing the gross storage. For a design drought of 25 years, 37 net storages (corresponding to net supply rate with no mandatory low flow release; and 9 supply rates equal to the net supply rate plus low flow release C1, C2, ..., C8, or $Q_{7,10}$ and recurrence intervals of 5, 10, 20, and 25 years) for each of the basic 2, 5, 10 and 20 percent of mean flow rate, are converted to gross storages. Similarly, gross storages are calculated for the design drought of 40 years. This yields the gross storage array STG (2, 148). The gross storage is calculated from the net storage as explained below.

Let S_o be the initial net storage. Initialize DELEV and DELSD equal to zero. Capacity-inflow ratio, CIR, equals ${}^{S_o}/_{I}$ where I is the mean inflow, in inches, to the reservoir. The annual capacity loss, ACL, equals

$$\text{ACL} = a(\text{CIR})^{\beta} \times 0.01 \times S_o$$

Capacity loss, in inches, from sediment over T years is

$$\text{CLSD} = \text{ACL} \times T$$

Then,

$$S_1 = S_o + \text{CLSD} - \text{DELSD}$$

and in ac ft, S_1 is

$$S_1 \text{ (ac ft)} = \frac{640\ A\ S_1}{12}$$

in which A is the drainage area in square miles. The corresponding water surface area, WSA, in acres (Dawes and Wathne, 1968) is

$$WSA = 0.23\ [S_1(\text{ac ft})]^{0.87}$$

and the capacity loss from evaporation, CLEV, in inches is given by

$$CLEV = EV \times 0.65 \times WSA/(A \times 640)$$

Therefore, gross capacity S_2 equals

$$S_2 = S_1 + CLEV - DELEV$$

The ratio of difference in S_2 and S_o to S_o, or DIF, is obtained from

$$DIF = (S_2 - S_o)/S_o$$

If this DIF < 0.01 S_o, the gross capacity equals S_2. If not, initialize

$$DELSD = CLSD$$

$$DELEV = CLEV$$

$$S_o = S_2$$

and start with computing ACL again. If the final S_o is less than the S_o with design drought recurrence interval of 25 or 40 years and with no mandatory low flow release, the final S_o (which is less sometimes for low flow releases at smaller recurrence intervals) is taken as equal to the S_o with design drought and zero low flow release.

The subroutine yields values of gross storage on the assumption that the reservoir can supply the net demand at the end of design drought, T, years even when the critical drought occurs in the Tth year. If the net storage for a supply of 2, 5, 10 or 20 percent of mean flow does not need any storage, no reservoir is needed and no calculations are done for that supply rate with or without low flow releases.

COST Subroutine

The capital reservoir cost in July 1980 dollars is computed (Singh and Adams, 1980) from

$$\text{Capital cost} = 26400\ (\text{storage})^{0.54} + 1.5\ (LC)\ WSA$$

in which storage is in ac-ft, WSA is water surface area in acres at normal pool level, and LC is the land cost in dollars per acre.

RESULT Subroutine

The subroutine prints the results in two series of tables: table 5 series for 25-year design drought and table 6 series for 40-year design drought. Tables 5.009 and 6.009 for the Little Wabash River below Clay City are included here as examples. The complete set of these tables for all the gaging stations analyzed is in Volume II of this report (Singh and Ramamurthy, 1981).

As shown in table 5.009, table 5 gives storage in ac-ft and the capital cost of reservoir and land in thousands of dollars for a net water supply of 2, 5, 10 and 20 percent of mean flow at a gaging station, with different levels of low flow releases:

Level	T, yrs	
0	25	The storage, S_o, is designed for a 25-year drought when no flow release is mandated.
$Q_{7,10}$	10	The storage, S, is designed for a 10-year drought with $Q_{7,10}$ as the minimum low flow release from the reservoir: if $S < S_o$, make $S = S_o$.
1*	5	The storage, S, is designed for a 5-year drought with C1 as the minimum low flow release from the reservoir; if $S < S_o$, make $S = S_o$.
	...	
	...	
	25	The storage, S, is designed for a 25-year drought with C1 as the minimum low flow release from the reservoir.

NOTE: Extra cost for providing a certain low flow release equals the cost with release minus the cost with no release or level zero.

* Level 1 through 8 denote low flow release C1 through C8.

TABLE 5.009 RESERVOIR STORAGE AND COST FOR A 25-YEAR RECURRENCE DROUGHT
USGS # 3379500 Little Wabash River below Clay City

		STORAGE IN ACRE-FEET FOR % MEAN FLOW USE OF				RESERVOIR COST IN 1000 $ FOR % MEAN FLOW USE OF			
LEVEL	T,YR	2	5	10	20	2	5	10	20
0	25	9379	19146	40272	91753	5164	8169	13347	23380
Q7,10	10	9379	19146	40272	91753	5164	8169	13347	23380
1	5	10028	19146	40272	91753	5388	8169	13347	23380
	10	12441	21741	40272	91753	6183	8875	13347	23380
	20	14472	25911	47169	95530	6814	9959	14843	24042
	25	15346	26940	49294	100347	7077	10217	15291	24876
2	5	9379	19146	40272	91753	5164	8169	13347	23380
	10	9964	19146	40272	91753	5366	8169	13347	23380
	20	11559	22135	43015	92253	5899	8980	13951	23468
	25	12414	23088	44805	95268	6175	9231	14338	23996
3	5	16414	24454	40272	91753	7392	9587	13347	23380
	10	20558	30500	49131	91945	8556	11091	15257	23413
	20	24419	36538	59334	109348	9578	12507	17338	26407
	25	25419	37902	62417	116723	9834	12817	17946	27637
4	5	10887	19146	40272	91753	5678	8169	13347	23380
	10	13639	23193	40761	91753	6559	9259	13456	23380
	20	15875	27741	49194	97819	7234	10417	15270	24440
	25	16743	28803	51482	102878	7487	10679	15746	25310
5	5	9379	19146	40272	91753	5164	8169	13347	23380
	10	9605	19146	40272	91753	5242	8169	13347	23380
	20	11138	21599	42428	91753	5761	8837	13822	23380
	25	11992	22539	44170	94577	6039	9087	14201	23875
6	5	9379	19146	40272	91753	5164	8169	13347	23380
	10	10698	19621	40272	91753	5615	8300	13347	23380
	20	12401	23238	44224	92212	6170	9271	14213	23460
	25	13278	24214	46112	96727	6447	9525	14618	24250
7	5	9379	19146	40272	91753	5164	8169	13347	23380
	10	10438	19310	40272	91753	5527	8214	13347	23380
	20	12095	22847	43795	93129	6072	9168	14120	23622
	25	12972	23814	45648	96199	6351	9421	14519	24158
8	5	9891	19146	40272	91753	5341	8169	13347	23380
	10	12250	21511	40272	91753	6122	8814	13347	23380
	20	14249	25621	46848	95168	6746	9885	14775	23979
	25	15123	26644	48948	99952	7010	10143	15219	24808

C1 = Median 31-day low flow during the period May - October.

C2 = Half median 31-day low flow during the period May - October.

C3 = Median 61-day low flow during the period May - October.

C4 = Half median 61-day low flow during the period May - October.

C5 = Flow at 90 percent duration using daily flows May - October.

C6 = Flow at 85 percent duration using daily flows May - October.

C7 = Flow at 90 percent duration using daily flows for the record.

C8 = Flow at 85 percent duration using daily flows for the record.

The flows corresponding to C1 through C8 at all the 123 gaging stations are given in table 2.

Table 6 gives the same information as in table 5 but with a design drought recurrence interval of 40 years.

Fish Suitability Program

A computer program was developed to determine the values of fish suitability for the juveniles and adults of the 9 target fish, for both riffle and pool conditions, with MIN and GM criteria at each of the 123 gaging stations and 8 low flow releases, C1 through C8. As explained previously, MIN refers to the smaller of the two fish suitability indexes for depth and velocity, and GM refers to the geometric mean of the two indexes, for a given flow condition.

Riffle Conditions

At a gaging station, the flow velocity, V, and depth, D, are read from the computer storage for each of the 8 low flow releases. The fish suitability or preference for each V and D is interpolated from the suitability data stored in the computer, for the juvenile and adult species of each of

TABLE 6.009 RESERVOIR STORAGE AND COST FOR A 40-YEAR RECURRENCE DROUGHT
USGS # 3379500 Little Wabash River below Clay City

		STORAGE IN ACRE-FEET FOR % MEAN FLOW USE OF				RESERVOIR COST IN 1000 $ FOR % MEAN FLOW USE OF			
LEVEL	T,YR	2	5	10	20	2	5	10	20
0	40	15169	28297	53572	121103	7024	10555	16175	28358
Q7,10	10	15169	28297	53572	121103	7024	10555	16176	28358
1	5	15609	28297	53572	121103	7155	10555	16176	28358
	10	18319	28388	53572	121103	7937	10577	16176	28358
	20	20623	32789	55042	121103	8574	11637	16476	28358
	40	23174	37486	63334	140379	9254	12722	18125	31452
2	5	15169	28297	53572	121103	7024	10555	16176	28358
	10	15586	28297	53572	121103	7148	10555	16176	28358
	20	17443	28891	53572	121103	7689	10700	16176	28358
	40	19290	32864	58225	130782	8209	11655	17117	29926
3	5	22510	31066	53572	121103	9079	11227	16176	28358
	10	27115	37664	57086	121103	10261	12763	16889	28358
	20	31181	44329	67863	121381	11255	14236	19000	28403
	40	35664	50768	78228	165133	12306	15599	20945	35271
4	5	16551	28297	53572	121103	7431	10555	16176	28358
	10	19625	29947	53572	121103	8301	10958	16176	28358
	20	22074	34756	57183	121103	8964	12097	16908	28358
	40	25039	39713	65820	145058	9737	13223	18608	32187
5	5	15169	28297	53572	121103	7024	10555	16176	28358
	10	15234	28297	53572	121103	7044	10555	16176	28358
	20	16984	28315	53572	121103	7557	10559	16176	28358
	40	18718	32204	57502	129425	8049	11499	16972	29708
6	5	15169	28297	53572	121103	7024	10555	16176	28358
	10	16390	28297	53572	121103	7385	10555	16176	28358
	20	18380	30075	53572	121103	7955	10989	16176	28358
	40	20460	34218	59714	133576	8530	11972	17413	30374
7	5	15169	28297	53572	121103	7024	10555	16176	28358
	10	16106	28297	53572	121103	7301	10555	16176	28358
	20	18049	29655	53572	121103	7861	10887	16176	28358
	40	20045	33738	59185	132583	8417	11860	17308	30215
8	5	15459	28297	53572	121103	7111	10555	16176	28358
	10	18111	28297	53572	121103	7878	10555	16176	28358
	20	20382	32477	55201	121103	8509	11563	16508	28358
	40	22877	37132	62940	139639	9176	12642	18048	31336

the 9 target fish. The suitability values are printed out in the Table 7 series (7.001 to 7.123). Table 7.009 is included here as an illustration. The set of 123 tables is included in Volume II of this report (Singh and Ramamurthy, 1981). The Q1 through Q8 are the same as C1 through C8 in table 2.

Pool Conditions

The average flow depth, d_p, in a pool is obtained from

$$d_p = d_r + b \log A$$

in which d_r is the average flow depth at the riffle, A is the drainage area in square miles, and b is a coefficient. The associated average flow velocity in the pool, v_p, is given by

$$v_p = (d_r \times v_r) / d_p$$

in which v_r is the average flow velocity at the riffle. With v_p and d_p, the fish suitabilities were calculated as for the riffle condition for 3 values of b: 0.50, 0.75, and 1.00. A set of 123 tables with b = 0.75, tables 8.001 to 8.123, is included in Volume II of this report (Singh and Ramamurthy, 1981). Table 8.009 is given here as an example. The Q1 through Q8 are the same as C1 through C8 in table 2.

TABLE 7.009 FISH SUITABILITY BASED ON V & D FROM HYDRAULIC GEOMETRY
USGS # 3379500 Little Wabash River below Clay City

FISH	TYPE	CRIT	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
1	JUVNL	MIN	.00	.00	.00	.00	.00	.00	.00	.00
		GM	.00	.00	.00	.00	.00	.00	.00	.00
	ADULT	MIN	.00	.00	.01	.00	.00	.00	.00	.00
		GM	.00	.00	.03	.00	.00	.00	.00	.00
2	JUVNL	MIN	.03	.06	.01	.02	.07	.04	.04	.03
		GM	.17	.20	.03	.15	.21	.19	.18	.17
	ADULT	MIN	.11	.15	.07	.10	.16	.14	.14	.11
		GM	.33	.39	.18	.31	.40	.37	.38	.33
3	JUVNL	MIN	.00	.00	.00	.00	.00	.00	.00	.00
		GM	.00	.00	.00	.00	.00	.00	.00	.00
	ADULT	MIN	.00	.00	.00	.00	.00	.00	.00	.00
		GM	.00	.00	.00	.00	.00	.00	.00	.00
4	JUVNL	MIN	.00	.00	.02	.00	.00	.00	.00	.00
		GM	.00	.00	.05	.00	.00	.00	.00	.00
	ADULT	MIN	.00	.00	.00	.00	.00	.00	.00	.00
		GM	.00	.00	.00	.00	.00	.00	.00	.00
5	JUVNL	MIN	.21	.10	.28	.25	.09	.13	.12	.20
		GM	.31	.26	.40	.32	.25	.28	.26	.31
	ADULT	MIN	.00	.00	.00	.00	.00	.00	.00	.00
		GM	.00	.00	.04	.00	.00	.00	.00	.00
6	JUVNL	MIN	.27	.15	.34	.33	.14	.19	.18	.26
		GM	.37	.31	.46	.39	.31	.34	.33	.37
	ADULT	MIN	.00	.00	.01	.00	.00	.00	.00	.00
		GM	.00	.00	.09	.00	.00	.00	.00	.00
7	JUVNL	MIN	.00	.00	.00	.00	.00	.00	.00	.00
		GM	.00	.00	.00	.00	.00	.00	.00	.00
	ADULT	MIN	.00	.00	.00	.00	.00	.00	.00	.00
		GM	.00	.00	.00	.00	.00	.00	.00	.00
8	JUVNL	MIN	.00	.00	.00	.00	.00	.00	.00	.00
		GM	.00	.00	.00	.00	.00	.00	.00	.00
	ADULT	MIN	.00	.00	.00	.00	.00	.00	.00	.00
		GM	.00	.00	.00	.00	.00	.00	.00	.00
9	JUVNL	MIN	.00	.00	.62	.12	.00	.00	.00	.00
		GM	.00	.00	.70	.31	.00	.00	.00	.00
	ADULT	MIN	.00	.00	.00	.00	.00	.00	.00	.00
		GM	.00	.00	.00	.00	.00	.00	.00	.00

1 = BLUEGILL, 2 = BLUNTNOSE, 3 = CARP,
4 = CHANNEL CAT, 5 = LARGEMOUTH BASS, 6 = SMALLMOUTH BASS,
7 = DRUM, 8 = WHITE BASS, 9 = WHITE CRAPPIE

TABLE 8.009 FISH SUITABILITY BASED ON ESTIMATED V & D IN POOLS
USGS # 3379500 Little Wabash River below Clay City

FISH	TYPE	CRIT	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
1	JUVNL	MIN	.45	.79	.12	.34	.86	.67	.72	.47
		GM	.67	.89	.35	.58	.93	.82	.85	.69
	ADULT	MIN	.80	.65	.88	.83	.62	.70	.68	.79
		GM	.89	.81	.92	.91	.79	.84	.82	.89
2	JUVNL	MIN	.00	.00	.00	.00	.00	.00	.00	.00
		GM	.00	.00	.00	.00	.00	.00	.00	.00
	ADULT	MIN	.00	.00	.00	.00	.00	.00	.00	.00
		GM	.00	.00	.00	.00	.02	.00	.00	.00
3	JUVNL	MIN	.84	.25	.98	.90	.21	.47	.38	.81
		GM	.92	.50	.98	.95	.46	.68	.61	.90
	ADULT	MIN	.48	.28	.97	.63	.26	.33	.31	.47
		GM	.69	.53	.98	.79	.51	.57	.55	.68
4	JUVNL	MIN	.08	.07	.08	.08	.07	.08	.07	.08
		GM	.21	.20	.23	.22	.20	.20	.20	.21
	ADULT	MIN	.18	.16	.23	.19	.16	.17	.17	.18
		GM	.42	.40	.48	.43	.40	.41	.41	.42
5	JUVNL	MIN	.98	.99	.93	.98	.99	.99	.99	.98
		GM	.99	1.00	.97	.99	1.00	1.00	1.00	.99
	ADULT	MIN	.23	.20	.29	.24	.19	.21	.20	.23
		GM	.48	.44	.53	.49	.44	.46	.45	.48
6	JUVNL	MIN	1.00	1.00	.99	1.00	1.00	1.00	1.00	1.00
		GM	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	ADULT	MIN	.59	.50	.75	.62	.49	.53	.52	.58
		GM	.66	.61	.75	.68	.60	.63	.62	.66
7	JUVNL	MIN	.82	.73	.95	.86	.71	.77	.75	.82
		GM	.91	.86	.97	.93	.85	.88	.87	.90
	ADULT	MIN	.67	.15	.95	.77	.09	.38	.28	.66
		GM	.82	.39	.97	.88	.29	.61	.53	.81
8	JUVNL	MIN	.79	.73	.88	.81	.72	.75	.75	.79
		GM	.89	.86	.94	.90	.85	.87	.86	.89
	ADULT	MIN	.02	.00	.17	.05	.00	.00	.00	.02
		GM	.15	.00	.42	.23	.00	.00	.00	.13
9	JUVNL	MIN	1.00	1.00	.99	1.00	1.00	1.00	1.00	1.00
		GM	1.00	1.00	.99	1.00	1.00	1.00	1.00	1.00
	ADULT	MIN	.64	.40	.85	.69	.36	.49	.45	.63
		GM	.80	.63	.91	.83	.60	.70	.67	.79

1 = BLUEGILL, 2 = BLUNTNOSE, 3 = CARP,
4 = CHANNEL CAT, 5 = LARGEMOUTH BASS, 6 = SMALLMOUTH BASS,
7 = DRUM, 8 = WHITE BASS, 9 = WHITE CRAPPIE

ANALYSES AND RESULTS

Information on capital costs of reservoirs to meet four water supply rates and eight low flow releases at various drought recurrence intervals was developed with the computer program for 112 gaging stations. The fish preferences for the nine target fish, both juveniles and adults, were developed for values of b (zero which is applicable to riffles, and 0.5, 0.75, and 1.0 for the pools) with both MIN and GM criteria, at 123 gaging stations, for each of the eight low flow releases considered. The costs and fish preferences were analyzed to examine the following:

1. How does the fish preference change with the value of b?
2. Do the pools provide most of the fish habitat during low flow conditio
3. What are the relative costs of providing low flow releases?
4. Do these costs vary with drainage area above the gaging station and with less variability in low flows?
5. What are the trade-offs between costs and fish habitat suitability in different parts of the state?
6. What data, field surveys, models, and analyses may be needed to analyze a river drainage system in terms of low flows, costs, and fish habitats?

Sensitivity Analysis: Parameter b

The fish suitability values for the juvenile and adult species of the nine target fish at each of the 123 gaging stations and eight low flow releases were calculated for four values of b: zero, which applies to the riffles; and 0.5, 0.75, and 1.0, which apply to the pools with increasing depth. Values of fish suitability are plotted against values of minimum flow release (ranging from 6.66 cfs to 38.50 cfs) in figure 8 for the juveniles and adults of the target fish as well as an average of these fish, for the Little Wabash River

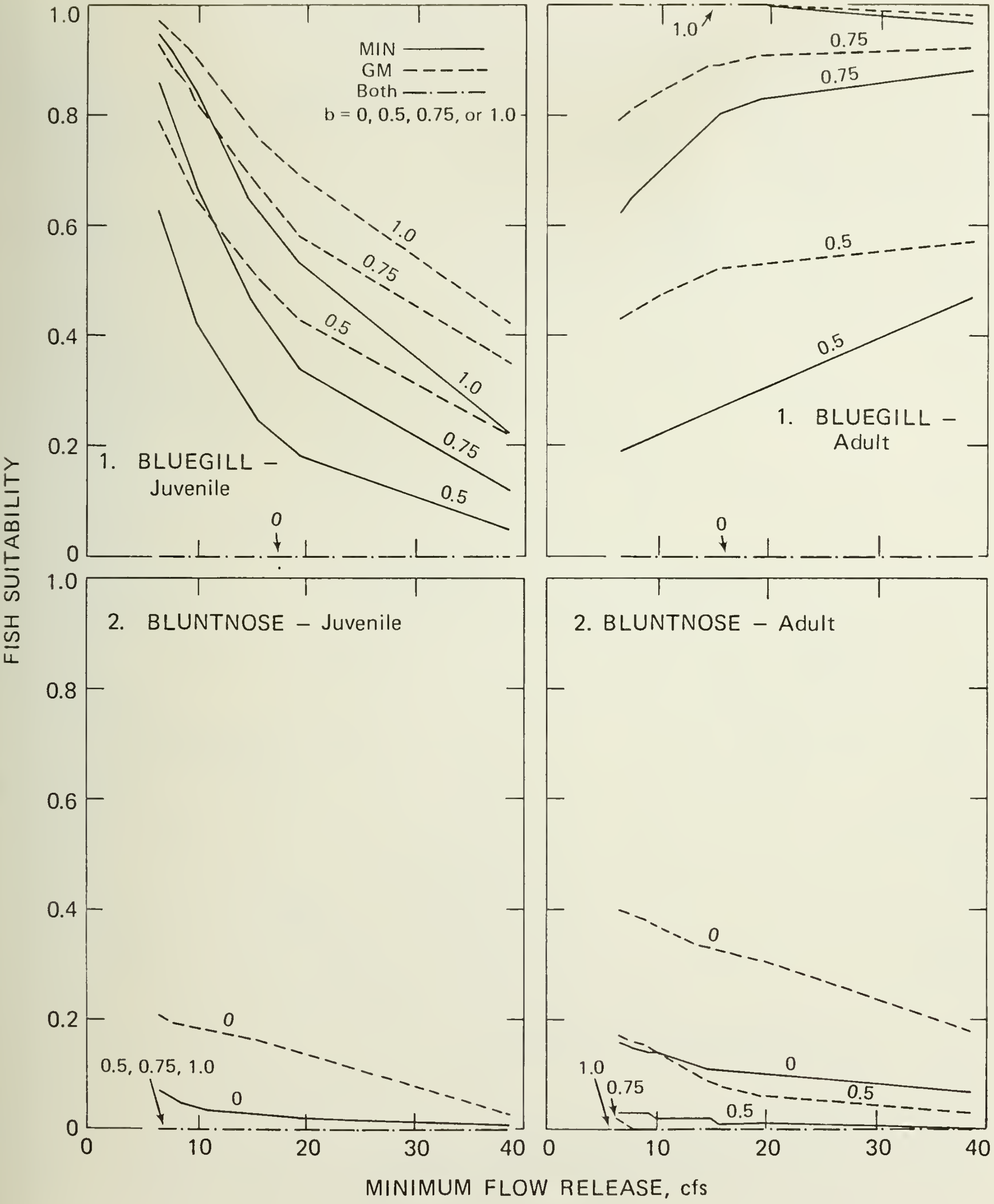


Figure 8. Fish suitability or preference for the low flow range at the Little Wabash River below Clay City (b = 0, 0.5, 0.75, and 1.0)

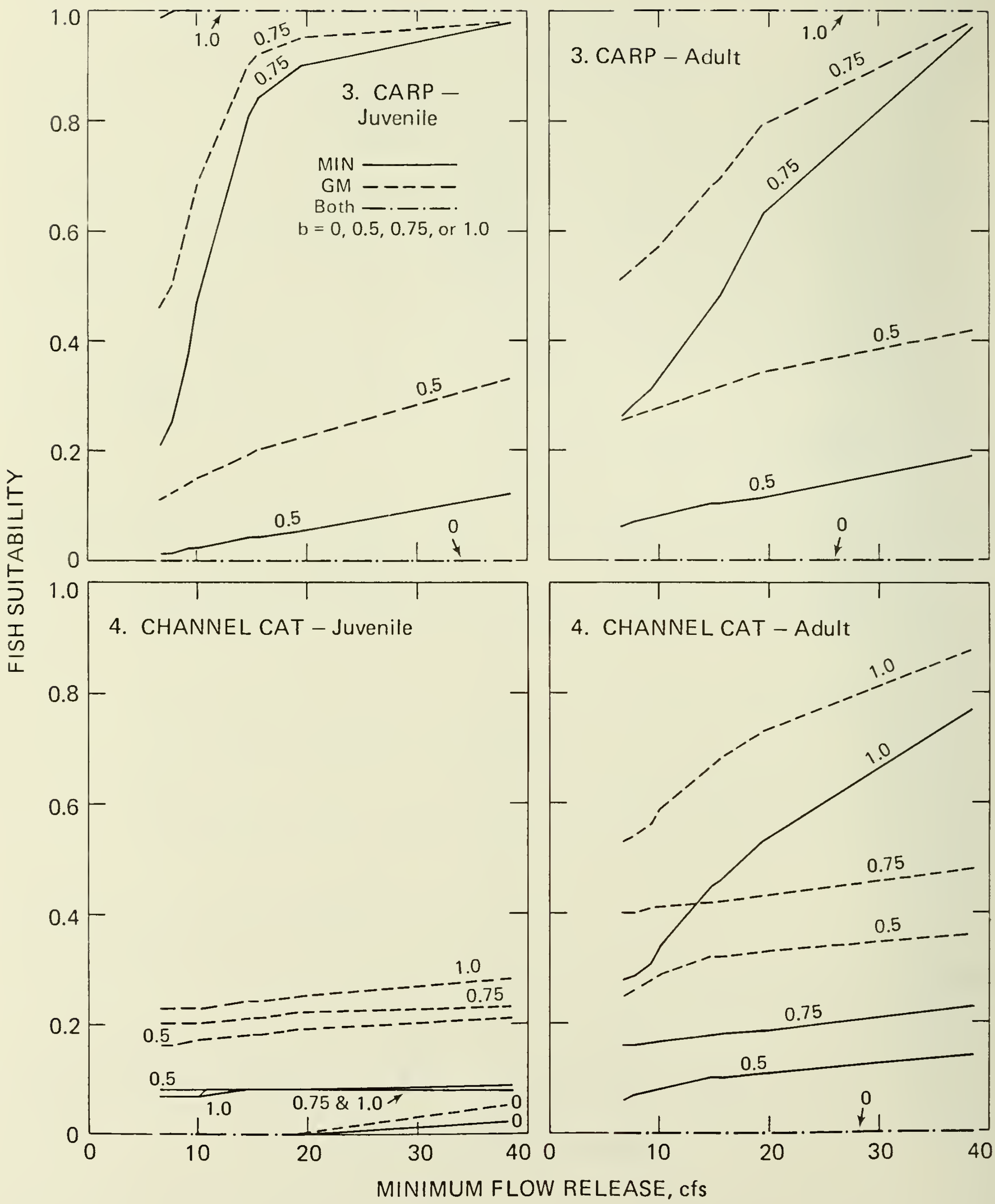


Figure 8. Continued

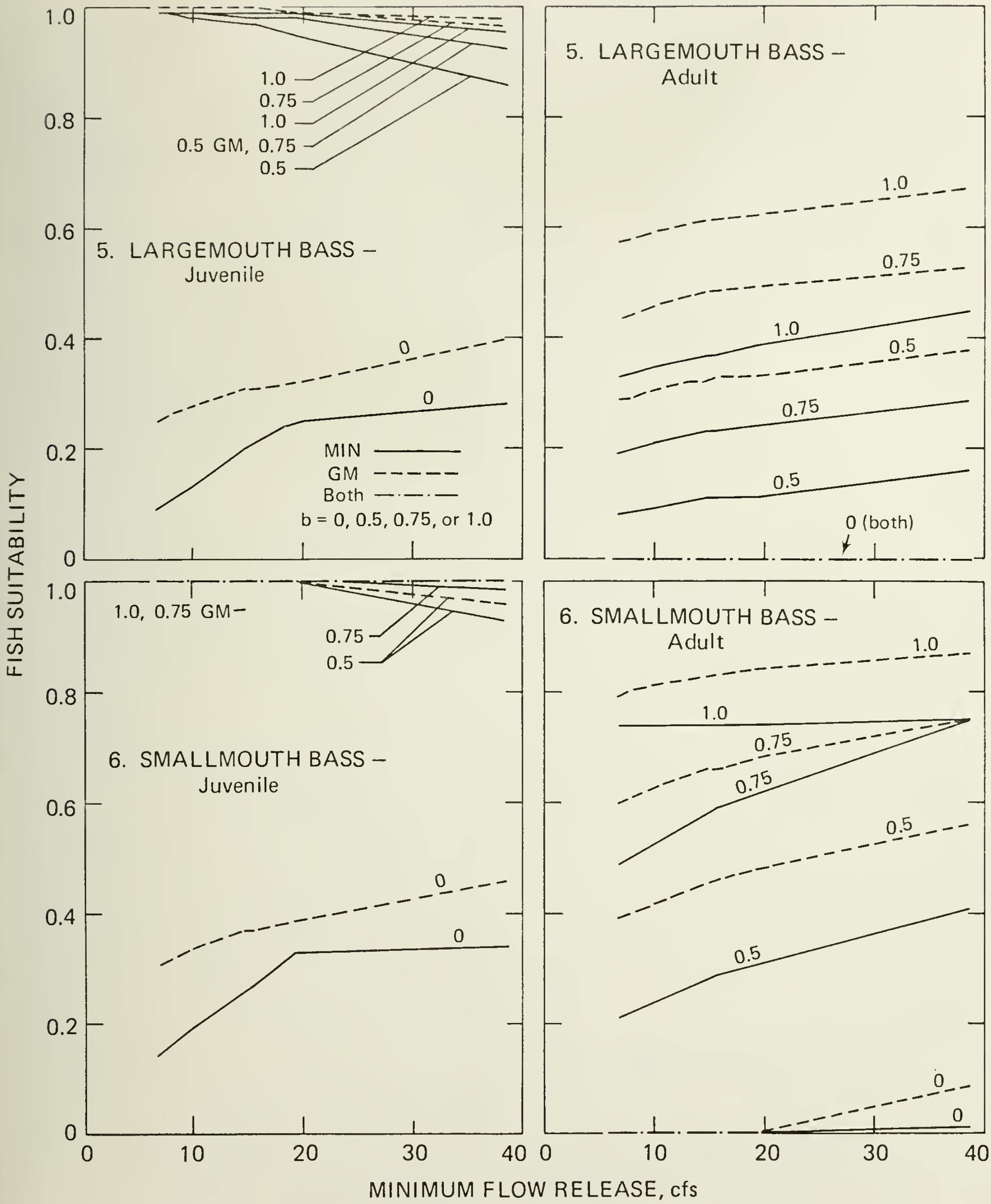


Figure 8. Continued

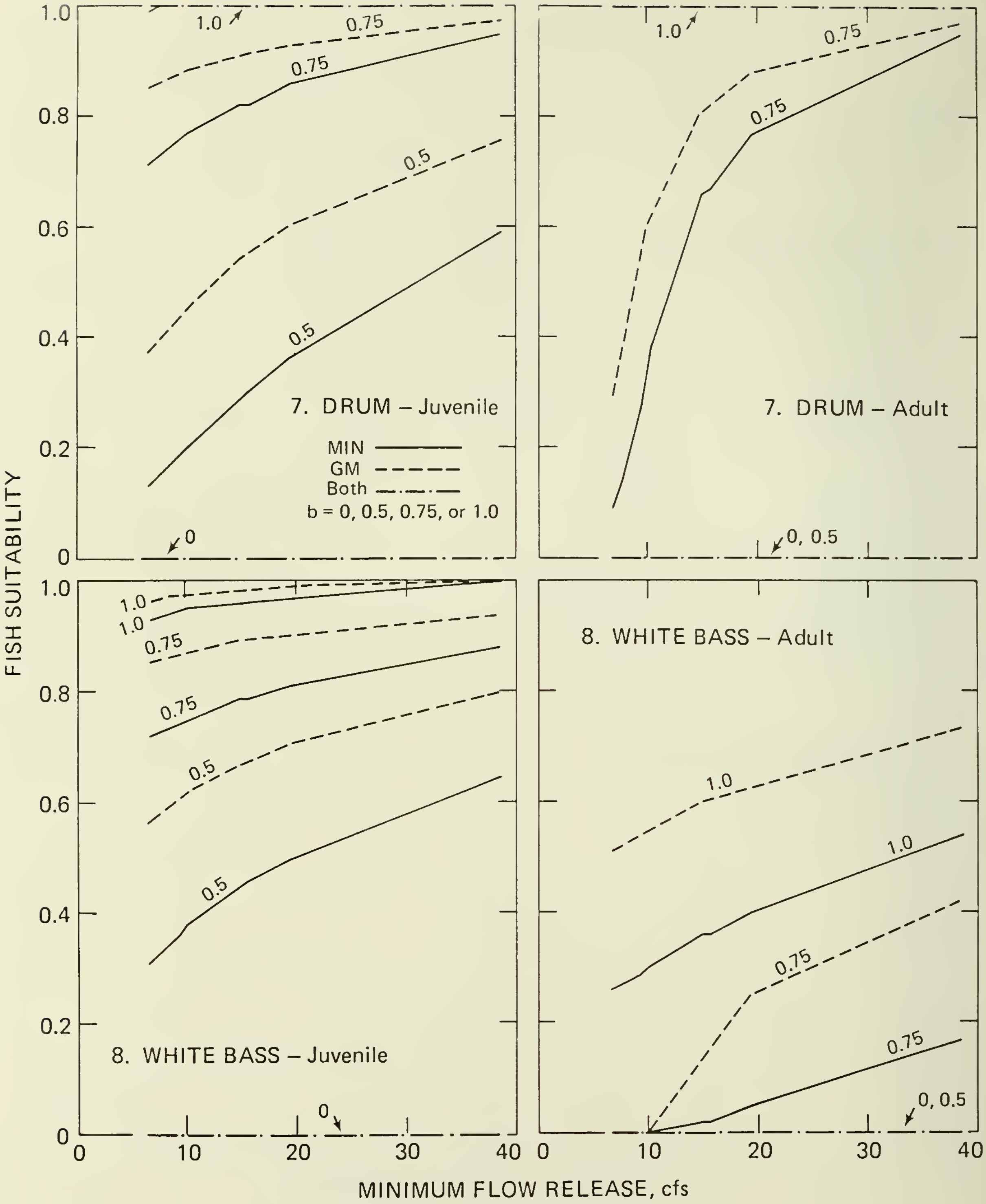


Figure 8. Continued

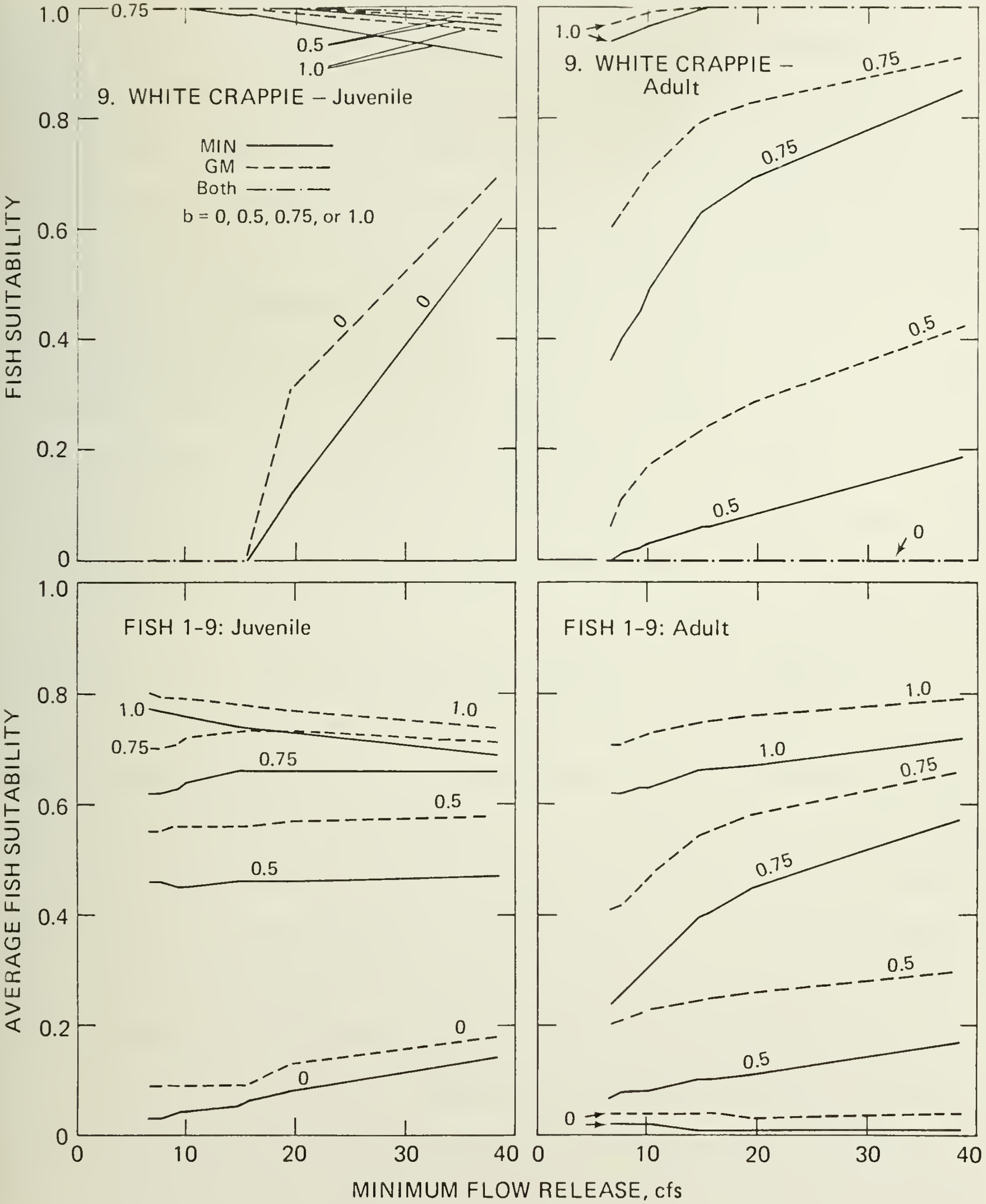


Figure 8. Concluded

below Clay City. The drainage area is 1131 square miles, the $Q_{7,10}$ equals 0.47 cfs, and the mean flow is 881 cfs, as given in table 1.

1) Bluegill. The juveniles have zero preference for the riffle condition because the flow velocity for the flow range exceeds 0.48 ft/sec. The preference increases with an increase in b because of larger depths and lower velocities at the low end of the flow range, but it decreases considerably as the flow increases. The GM criterion gives higher values than the MIN. The adults, too, have zero preference for the riffle condition because the flow depth is less than 1.0 ft. The preference increases with an increase in b and an increase in discharge to about 20 cfs. For the bluegill fish, a minimum flow release of 15 to 20 cfs is indicated during a drought period. This range yields a MIN of about 0.8 with b = 0.75, and 1.0 with b = 1.0 for the adult fish. The corresponding values are about 0.4 and 0.6 for the juveniles.

2) Bluntnose. The juveniles' GM preference for the riffles decreases from 0.21 to 0.03 and the MIN preference decreases from 0.07 to 0.01 with an increase in flow release from 6.66 to 38.5 cfs. The preference is zero for the pools with b = 0.5, 0.75, or 1.00 because of flow depths exceeding 1.5 ft. The adults' GM preference for b = 0 decreases from 0.40 to 0.18 and their MIN preference decreases from 0.16 to 0.07. The preferences for b = 0.5, 0.75, or 1.00 are either small or zero. Thus, the Little Wabash River below Clay City does not provide a desirable habitat for the bluntnose because of the requirements of low velocities and depths.

3) Carp. The juveniles have zero preference for the riffle condition because of small flow depths (0.57-0.94 ft). For the pool conditions, the preference increases greatly from b = 0.5 to 0.75 and it is 1.0 for the entire flow range for b = 1.0. A low flow release of 20 cfs and b = 0.75 give GM

and MIN values of 0.95 and 0.90, respectively. The adults, also, have a zero preference for the riffle condition, but the preferences for the pool condition increase considerably with increases in b and in flow release. For the range of low flow releases under consideration, both GM and MIN are 1.0 with b = 1.0. The corresponding values with b = 0.75 are 0.79 and 0.64 with 20 cfs, and 0.98 and 0.97 with 38.5 cfs.

4) Channel Cat. The juveniles have practically zero preference for the riffle condition because of small flow depths. For the pool condition, the MIN preference is about 0.08 for b = 0.5, 0.75 or 1.00, but the GM slightly increases from 0.20 to 0.23, with an increase in low flow release. The adults have a zero preference for the riffle condition but the preference for the pool condition increases considerably with increases in b and in flow release. The fish like large depths and low velocities. With b = 0.75, the MIN and GM preferences are 0.19 and 0.43 with 20 cfs, and 0.23 and 0.48 with 38.5 cfs. With b = 1.0, the MIN and GM preferences are 0.54 and 0.73 with 20 cfs, and 0.77 and 0.88 with 38.5 cfs.

5) Largemouth Bass. The juveniles have MIN and GM preferences which vary from 0.25 to 0.28 and from 0.32 to 0.40, respectively, with flow releases from 20 to 38.5 cfs at the riffle. For the pools, with b = 0.5, 0.75 or 1.00, the preferences range from 0.86 to 1.0 for the low flow range under consideration. A flow release of $\leq$ 20 cfs is indicated. The adults have a zero preference for the riffles but their preference increases considerably with an increase in b and somewhat · slowly with an increase in flow. The MIN and GM preferences with b = 0.75 are 0.24 and 0.49 with 20 cfs, and 0.29 and 0.53 with 38.5 cfs. These preferences with b = 1.0 are 0.39 and 0.62 with 20 cfs, and 0.45 and 0.67 with 38.5 cfs.

6) Smallmouth Bass. The juveniles have MIN and GM preferences which vary from 0.33 to 0.34 and from 0.39 to 0.46, respectively, with flow releases from 20 to 38.5 cfs at the riffle. For the pools with b = 0.5, 0.75, or 1.0, the preferences range from 0.93 to 1.00 for the low flow range. A flow release of 15 to 20 or less cfs is indicated. The adults have a zero preference for the riffles for flow releases $\leq$ 20 cfs, but their preference increases considerably with increases in b and in flow. The MIN and GM preferences with b = 0.75 are 0.62 and 0.68 with 20 cfs, and 0.75 and 0.75 with 38.5 cfs. These preferences with b = 1.0 are 0.74 and 0.84 with 20 cfs, and 0.75 and 0.87 with 38.5 cfs.

7) Drum. The juveniles have zero preference for the riffle condition, but their preference for the pools increases considerably with an increase in b. For 20 cfs flow release, the MIN preferences are 0.35, 0.84, and 1.00, and the GM preferences are 0.60, 0.93, and 1.00, for b = 0.5, 0.75 and 1.0, respectively. For 38.5 cfs, the corresponding values are 0.59, 0.95 and 1.0, and 0.76, 0.97 and 1.0. The adults have a zero preference for both riffles and pools with b = 0.5. However, their preference increases rapidly as the flow release increases with b = 0.75, and it is 1.0 with b = 1.0 for both MIN and GM for the entire low flow range. With b = 0.75, the MIN and GM are 0.78 and 0.88 at 20 cfs, and 0.95 and 0.97 at 38.5 cfs.

8) White Bass. The juveniles have zero preference for the riffles because of the low depth of flow. However, the preference increases with an increase in b in the pools and with an increase in flow release. The MIN and GM preferences for b = 0.75 are 0.81 and 0.90 at 20 cfs, and 0.88 and 0.94 at 38.5 cfs. Both MIN and GM preferences are close to 1.0 with b = 1.0. The adults have a zero preference for both riffle and pool with b = 0.5. The fish requires larger depth of flow. The MIN and GM preferences

with b = 0.75 are 0.05 and 0.26 for 20 cfs and 0.17 and 0.42 for 38.5 cfs. With b = 1.0, the corresponding values are 0.40 and 0.63 for 20 cfs and 0.54 and 0.73 for 38.5 cfs.

9) White Crappie. The juveniles' MIN preference for the riffle condition increases from 0.0 to 0.62 with the flow release increasing from 15.5 to 38.5 cfs. Their preferences for the pools (b = 0.5, 0.75, or 1.0) lie within 0.91 and 1.0 and decrease with an increase in flow. A 10-20 cfs flow release will be adequate. The adults have zero preference for the riffle condition because of low depths of flow. Their preference increases considerably with an increase in b and to some extent with an increase in the flow release. The MIN and GM preferences with b = 0.75 are 0.70 and 0.83 at 20 cfs and 0.85 and 0.91 at 38.5 cfs. These preferences with b = 1.0 are 1.0 for a flow of 15 to 38.5 cfs.

The fish suitability or preference values of the nine target fish in the Little Wabash River below Clay City indicate that generally a flow of 15 to 20 cfs during drought conditions will be adequate to sustain the fish with the exception of bluntnose (for which the conditions are quite different than those for the others). The preferences for the pools with b = 0.75 and 1.00 are not as much different from each other as are those with b = 0.50 and 0.75. The preferences are higher with b = 1.0 than with 0.75. The pools may have depths which correspond to b varying from 0.25 to 1.25. If a probabilistic distribution of depths within a pool were available, the pool would show a proliferation of one fish in one area and another in another area of the pool. The value of b = 0.75 is considered a reasonable estimate but it needs to be checked for different streams.

The average fish suitability or preference, as a mean of the nine individual preferences, are shown in figure 8 for each flow release and b value.

For the juveniles, the average preferences for b = 0.75 are 0.66 MIN and 0.72 GM for 15 to 38.5 cfs flow. For the adults, the average preference for b = 0.75 increases from 0.46 to 0.57 with MIN and 0.58 to 0.66 with GM, as the flow release increases from 20 to 38.5 cfs.

Low Flow Release Costs

Capital cost of the reservoir needed to meet the desired water supply at the design drought recurrence interval (25 or 40 years) is denoted by C_o. The capital cost of the reservoir needed to meet the desired water supply and the flow release (C1 through C8, or level 1 through 8) at the design drought recurrence interval is denoted by C. The increase in cost in providing the low flow release for the same design drought is, then, $C - C_o$. The ratio ${}^{C}/_{C_o}$, CR, is useful for plotting increases in costs with increases in low flow releases for the four water supply rates of 2, 5, 10 and 20 percent of mean flow. The incremental capital cost, ΔC, is obtained from

$$\Delta C = ({}^{C}/_{C_o} - 1)\ C_o = (CR - 1)\ C_o$$

In order to provide a space sampling, five river basins (each with 3 gaging stations) were selected. These are:

		sq mi	$Q_{7,10}$ cfs
I.	Little Wabash River Basin		
	009 Little Wabash River below Clay City	1131	0.47
	010 Skillet Fork at Wayne City	464	0.00
	011 Little Wabash River at Carmi	3102	5.70
II.	Kishwaukee River Basin		
	020 Kishwaukee River at Belvidere	538	34.3
	021 S.B. Kishwaukee River near Fairdale	387	9.90
	022 Kishwaukee River near Perryville	1099	62.3
III.	Bay Creek Basin		
	039 Hadley Creek at Kinderhook	72.7	0.00
	040 Bay Creek at Pittsfield	39.4	0.00
	041 Bay Creek at Nebo	161	0.00

IV.	Vermilion River Basin	sq mi	$Q_{7,10}$ cfs
079	N.F. Vermilion River near Charlotte	186	0.00
080	Vermilion River at Pontiac	579	0.20
081	Vermilion River at Lowell	1278	7.30
V.	S.F. Sangamon River Basin		
096	Flat Branch near Taylorville	276	0.00
097	S.F. Sangamon River at Kincaid	562	0.79
098	S.F. Sangamon River near Rochester	867	0.84

I. *Little Wabash River Basin.* The range of the low flow releases for the 3 gaging stations in this basin are:

No.	Stream and gaging station	Range, cfs
009	Little Wabash River below Clay City	6.66-38.50
010	Skillet Fork at Wayne City	0.74-7.78
011	Little Wabash River at Carmi	24.00-123.00

The lowest flow release corresponds to C5 and the highest to C3.

The cost ratios, CR, for the four supply rates and range of low flow releases for the above three stations are indicated in figures 9, 10, and 11. For providing 19.3 cfs low flow release, the extra cost for the four supply rates and 25-year design drought for station 009 are:

Supply rate, %	ΔC, 10^6 \$
2	2.323
5	2.510
10	2.399
20	1.930

Thus, the ΔC varies from 2 to 2.5 million dollars but the cost ratio is 1.45, 1.31, 1.18, and 1.08 for supply rates of 2, 5, 10, and 20 percent. The cost ratio increases with decreases in supply rate and with increases in low flow release. The values of C_o with 40-year drought are higher than for the 25-year drought and the difference increases with increases in the supply rate. As a comparison, the extra cost of providing 19.3 cfs low flow release with 40-year design drought for station 009 is given on page 85.

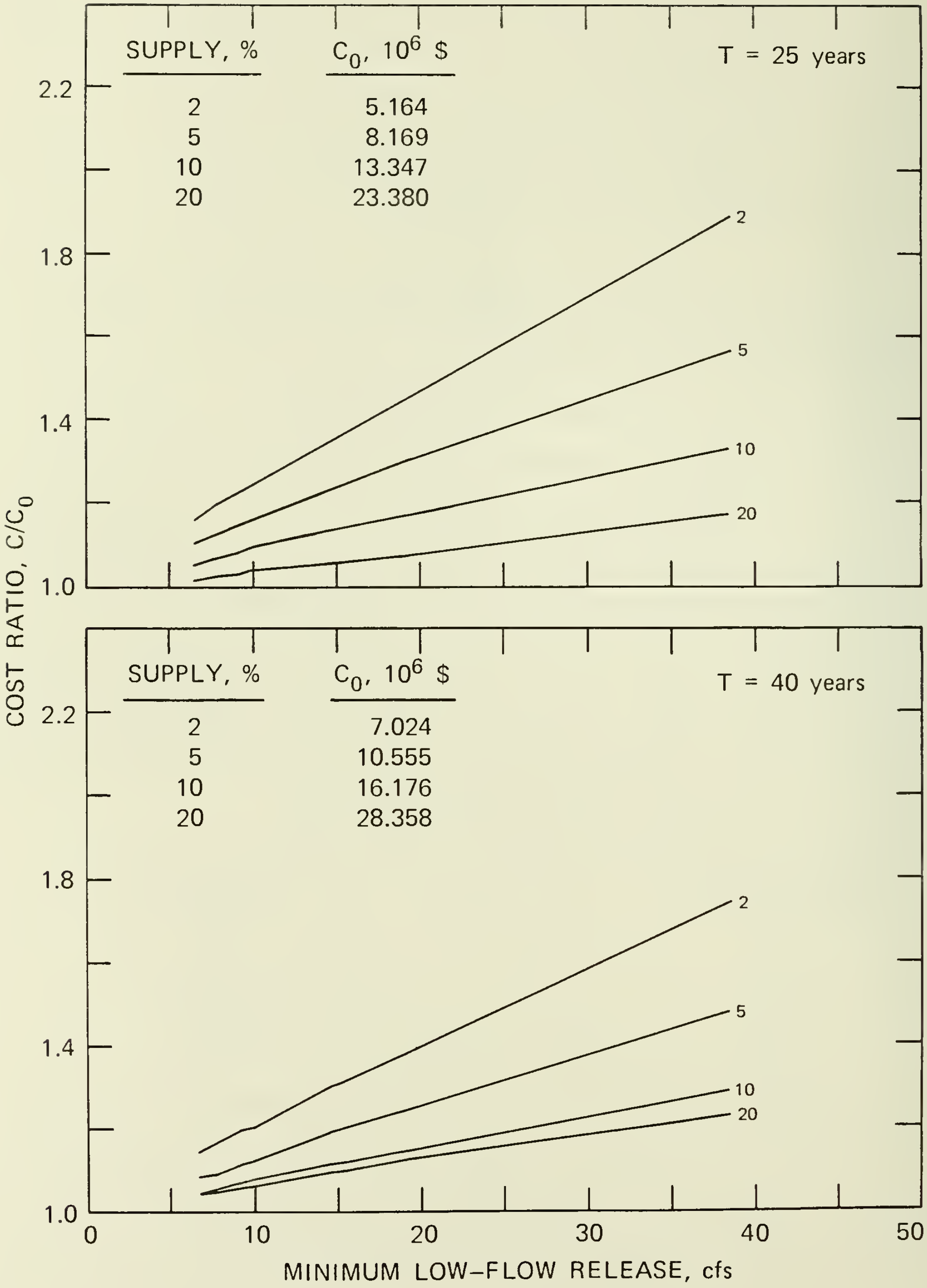


Figure 9. Cost ratio vs. low-flow release curves: Little Wabash River below Clay City

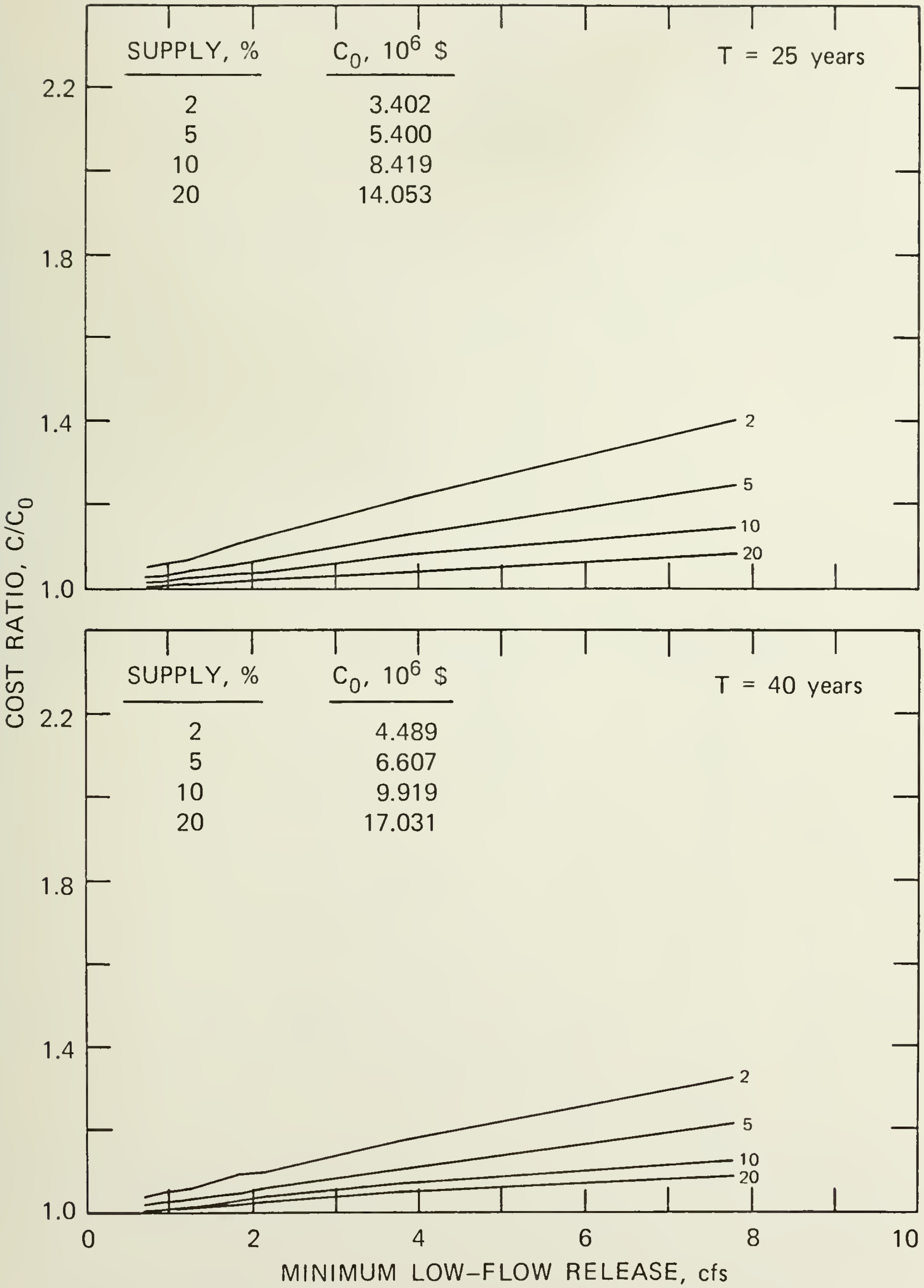


Figure 10. Cost ratio vs. low-flow release curves: Skillet Fork at Wayne City

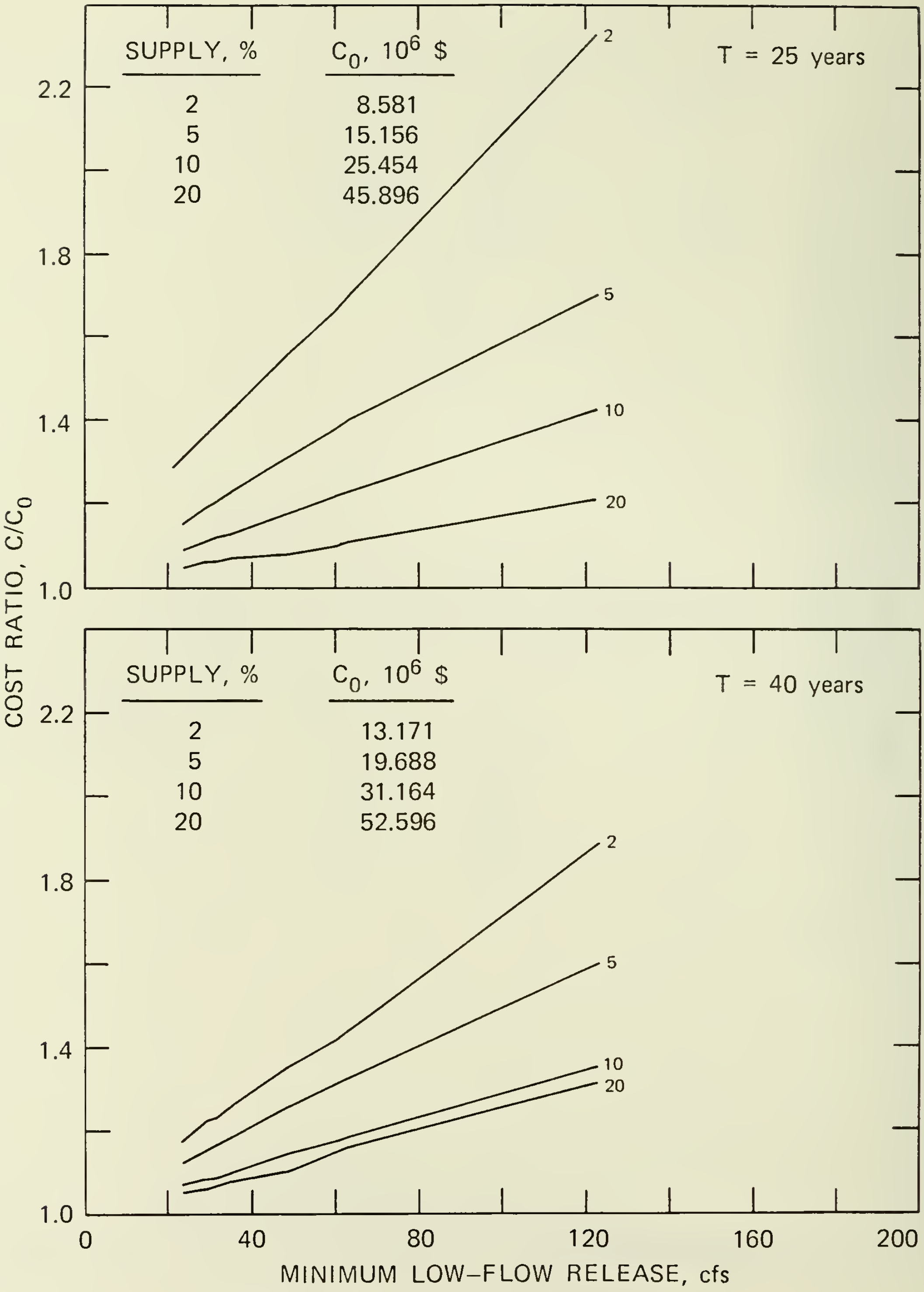


Figure 11. Cost ratio vs. low-flow release curves: Little Wabash River at Carmi

Supply rate, %	ΔC, 10^6\$
2	2.715
5	2.668
10	2.432
20	3.829

The low flow range, 0.74 - 7.78 cfs, for the Skillet Fork at Wayne City (figure 10) provides cost ratios ≤ 1.41 which are smaller than for station 009. The relatively high flow range, 24-130 cfs, for the Little Wabash River at Carmi (figure 11) provides cost ratios ≤ 2.33. The extra capital cost per cfs of flow release for a given design drought can be estimated from figures 9, 10, and 11 for the net water supply rates of 2, 5, 10, and 20 percent. Some approximate estimates are:

Station	T, years	Supply rate, %	ΔC per cfs, 10^6\$
009	25	2	0.12
		5	0.12
		10	0.12
		20	0.12
010	25	2	0.18
		5	0.17
		10	0.17
		20	0.16
011	25	2	0.095
		5	0.092
		10	0.092
		20	0.082

The unit cost is higher for the Skillet Fork, which has more variable low flow, than for the other two. The unit costs decrease with increase in drainage area.

II. *Kishwaukee River Basin.* The range of the low flow releases for the three gaging stations in this basin are:

No.	Stream and gaging station	Range, cfs
020	Kishwaukee River at Belvidere	36.90-92.00
021	S.B. Kishwaukee River near Fairdale	10.10-28.60
022	Kishwaukee River near Perryville	69.00-156.00

The lowest low flow release corresponds to C2 and the highest to C3. The lowest flow releases are somewhat higher than the $Q_{7,10}$ of 34.3, 9.9, and 62.3 cfs.

The cost ratios, CR, for the 2 or 3 supply rates and range of low flow releases for the above three stations are shown in figures 12, 13, and 14. The curves for 2 and 5 percent supply rates for stations 020 and 022 and the curve for 2 percent for station 021 are not shown because these supplies can be developed from the streams without any impoundments. The extra capital cost per cfs of flow release for a 25-year design drought for net water supply rates of 10 and 20 percent of mean flow, as developed from these figures, are given below for the three stations.

Station	T, years	Supply rate, %	ΔC per cfs, 10^6 \$
020	25	10	0.13
		20	0.13
021	25	10	0.15
		20	0.14
022	25	10	0.11
		20	0.11

The unit cost decreases with increase in low streamflows and decrease in their variability, or with increase in drainage area.

III. *Bay Creek Basin.* The range of the low flow releases for the 3

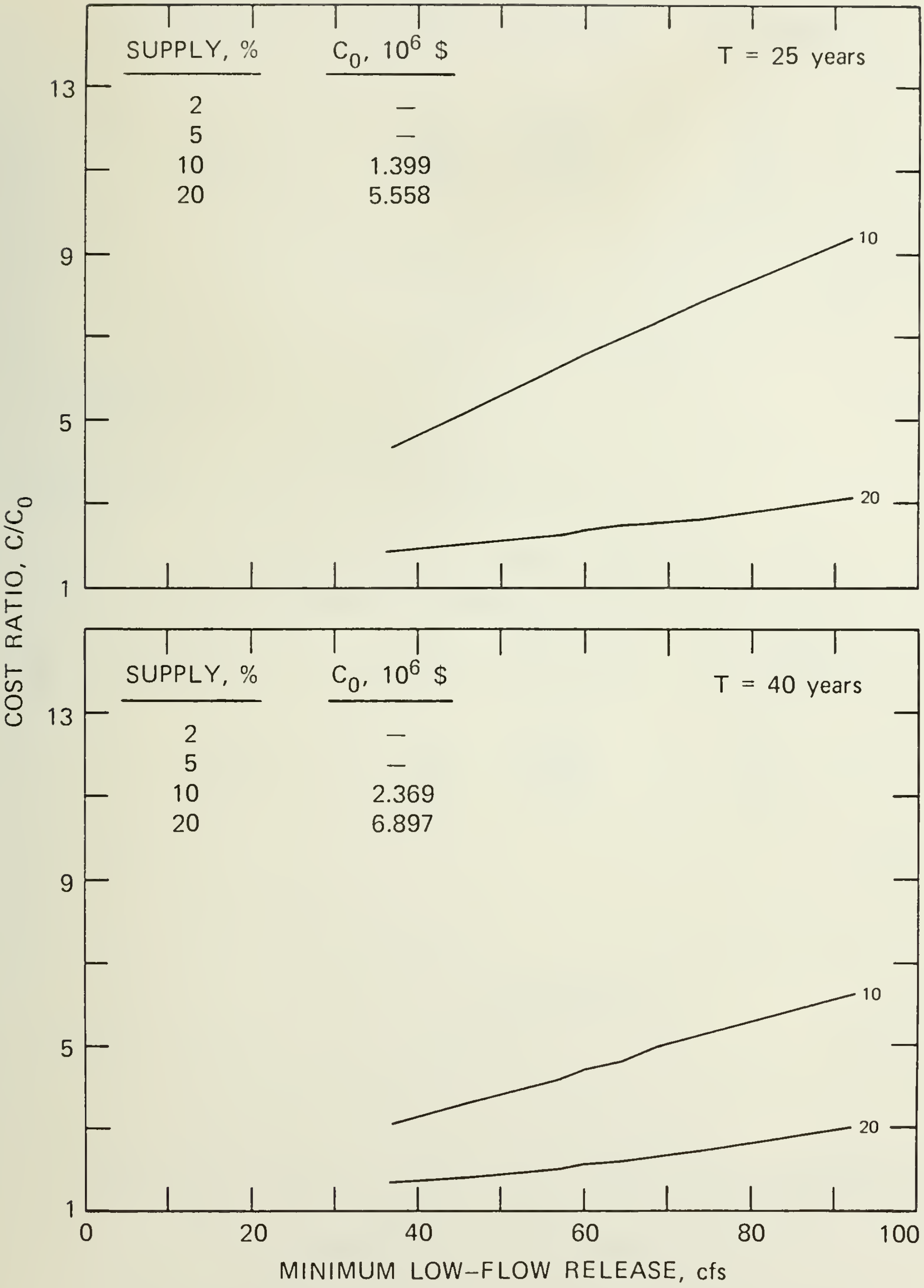


Figure 12. Cost ratio vs. low-flow release curves: Kishwaukee River at Belvidere

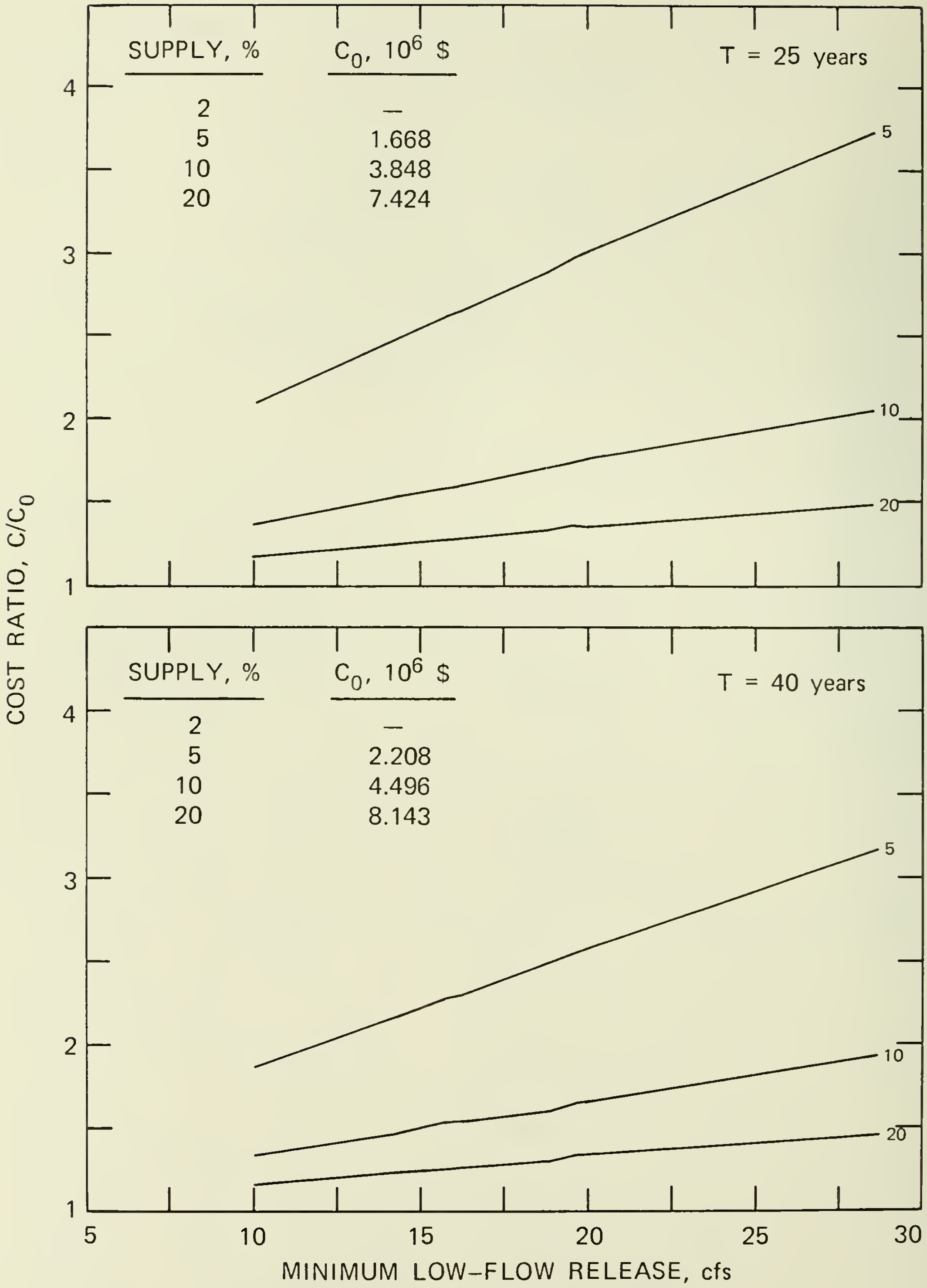


Figure 13. Cost ratio vs. low-flow release curves: S.B. Kishwaukee River near Fairdale

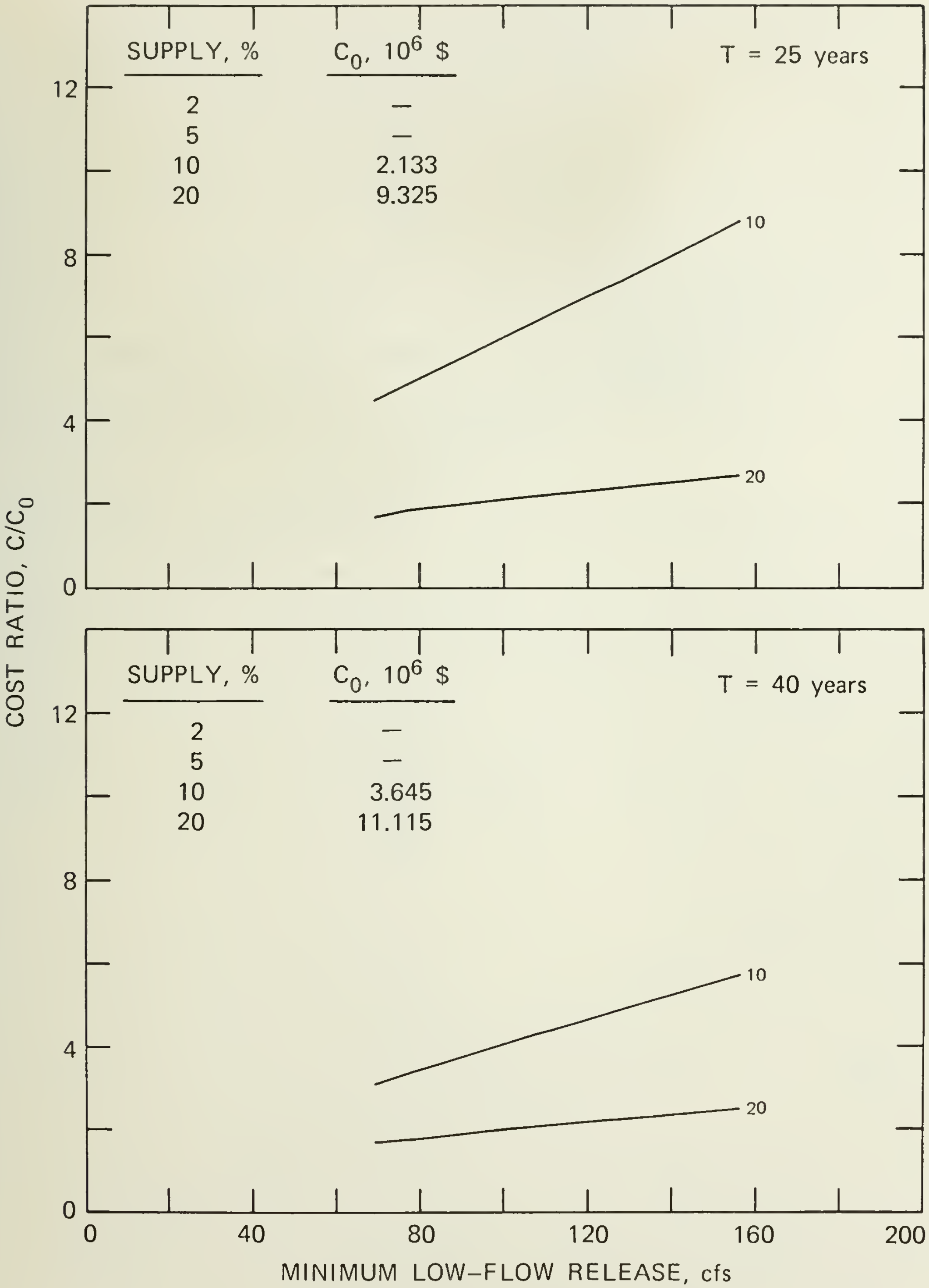


Figure 14. Cost ratio vs. low-flow release curves: Kishwaukee River near Perryville

gaging stations in this basin are:

No.	Stream and gaging station	Range, cfs
039	Hadley Creek at Kinderhook	0.19-4.50
040	Bay Creek at Pittsfield	0.15-1.91
041	Bay Creek at Nebo	0.69-10.50

The lowest flow release corresponds to C5 and the highest to C3. The 7-day 10-year low flow at each of these stations is zero. The range of drainage areas for this basin, 39.4 to 161 sq mi, is much smaller than for the other 4 basins.

The cost ratios, CR, for the four supply rates and range of low flow releases for the above three stations are shown in figures 15, 16, and 17. The extra capital cost per cfs of flow release for a 25-year design drought for net water supply rates of 2, 5, 10, and 20 percent of mean flow, as developed from these figures, are given below for the three stations.

Station	T, years	Supply rate, %	ΔC per cfs, 10^6 $
039	25	2	0.27
		5	0.27
		10	0.32
		20	0.44
040	25	2	0.41
		5	0.43
		10	0.44
		20	0.60
041	25	2	0.23
		5	0.26
		10	0.31
		20	0.40

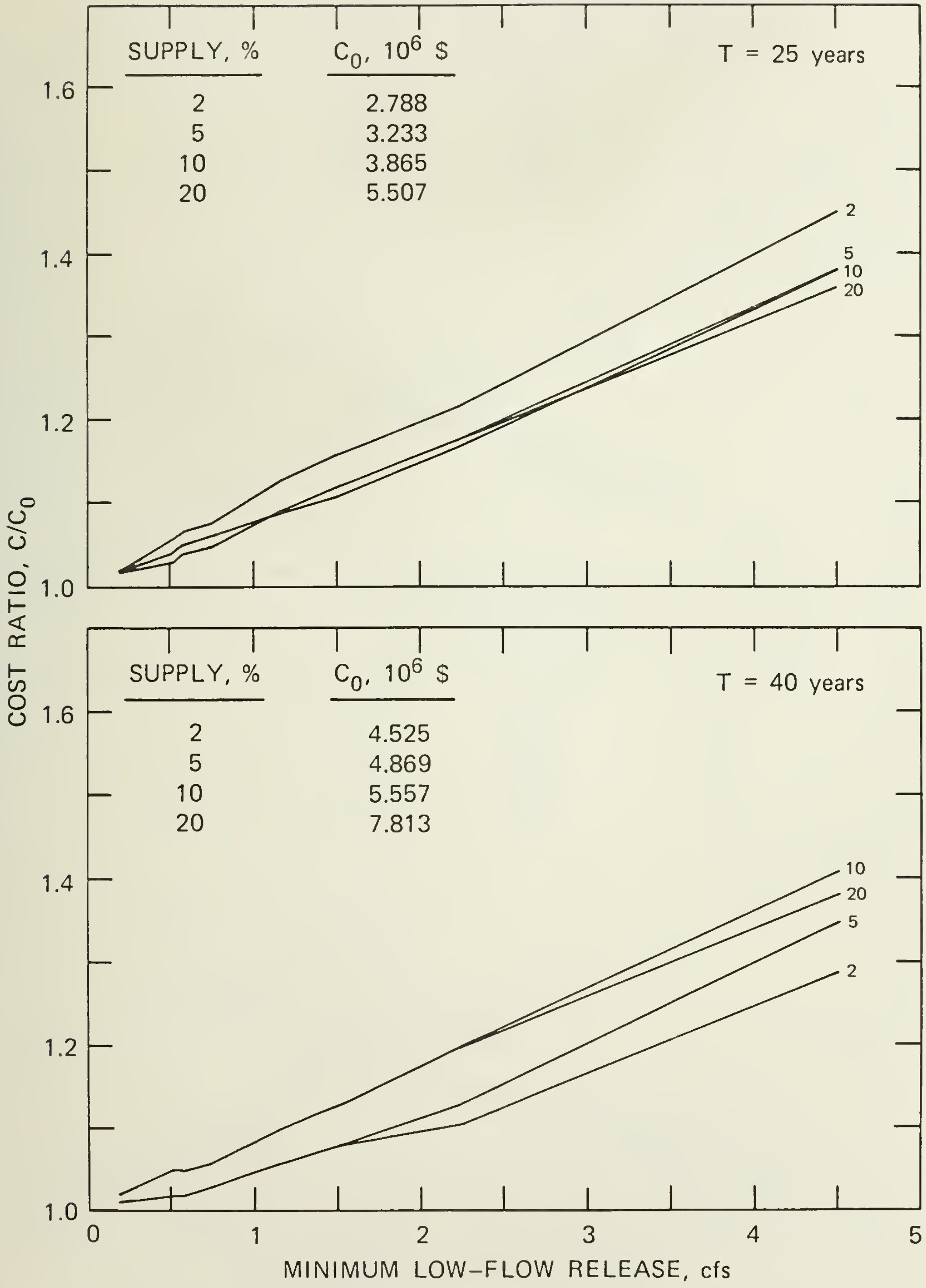


Figure 15. Cost ratio vs. low-flow release curves: Hadley Creek at Kinderhook

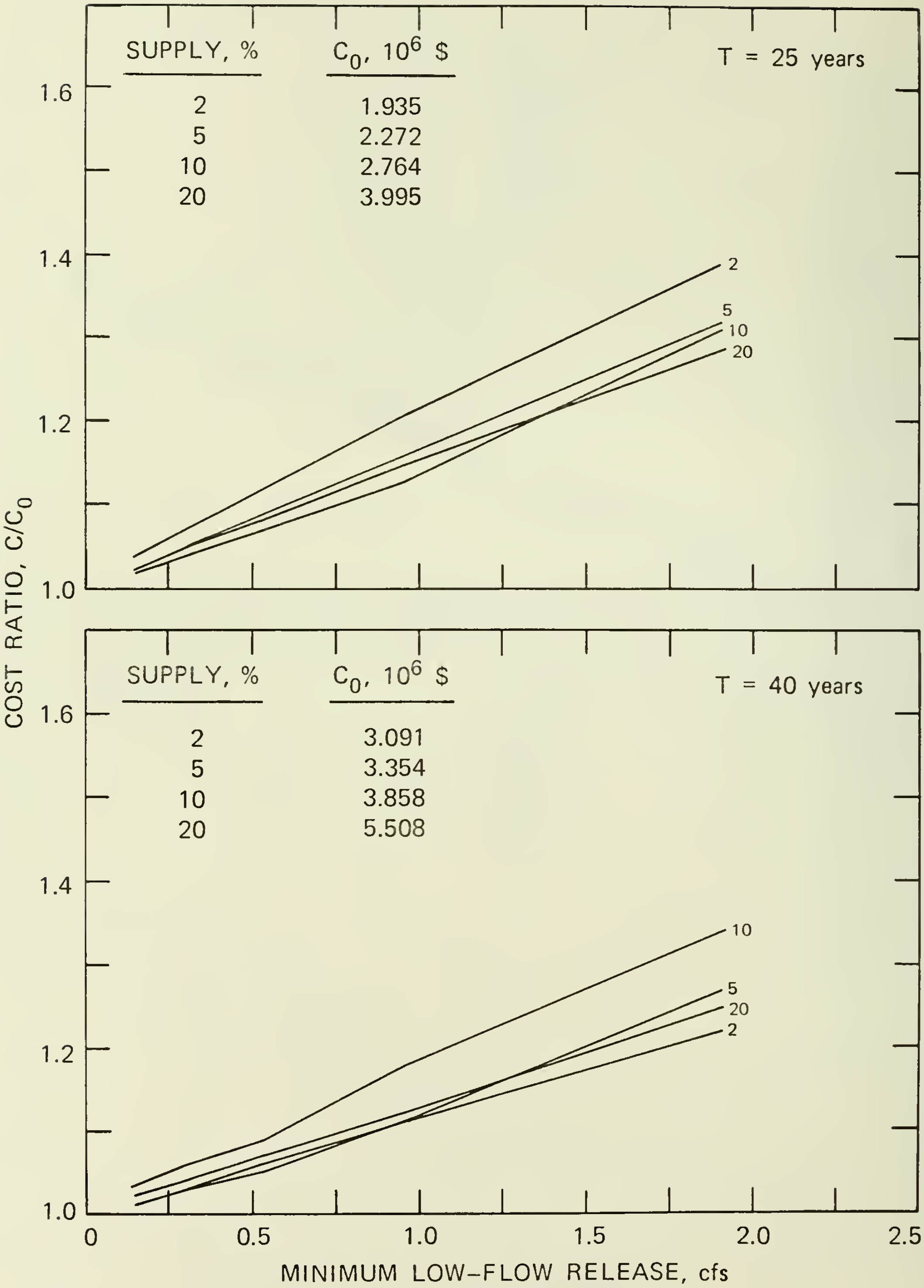


Figure 16. Cost ratio vs. low-flow release curves:
Bay Creek at Pittsfield

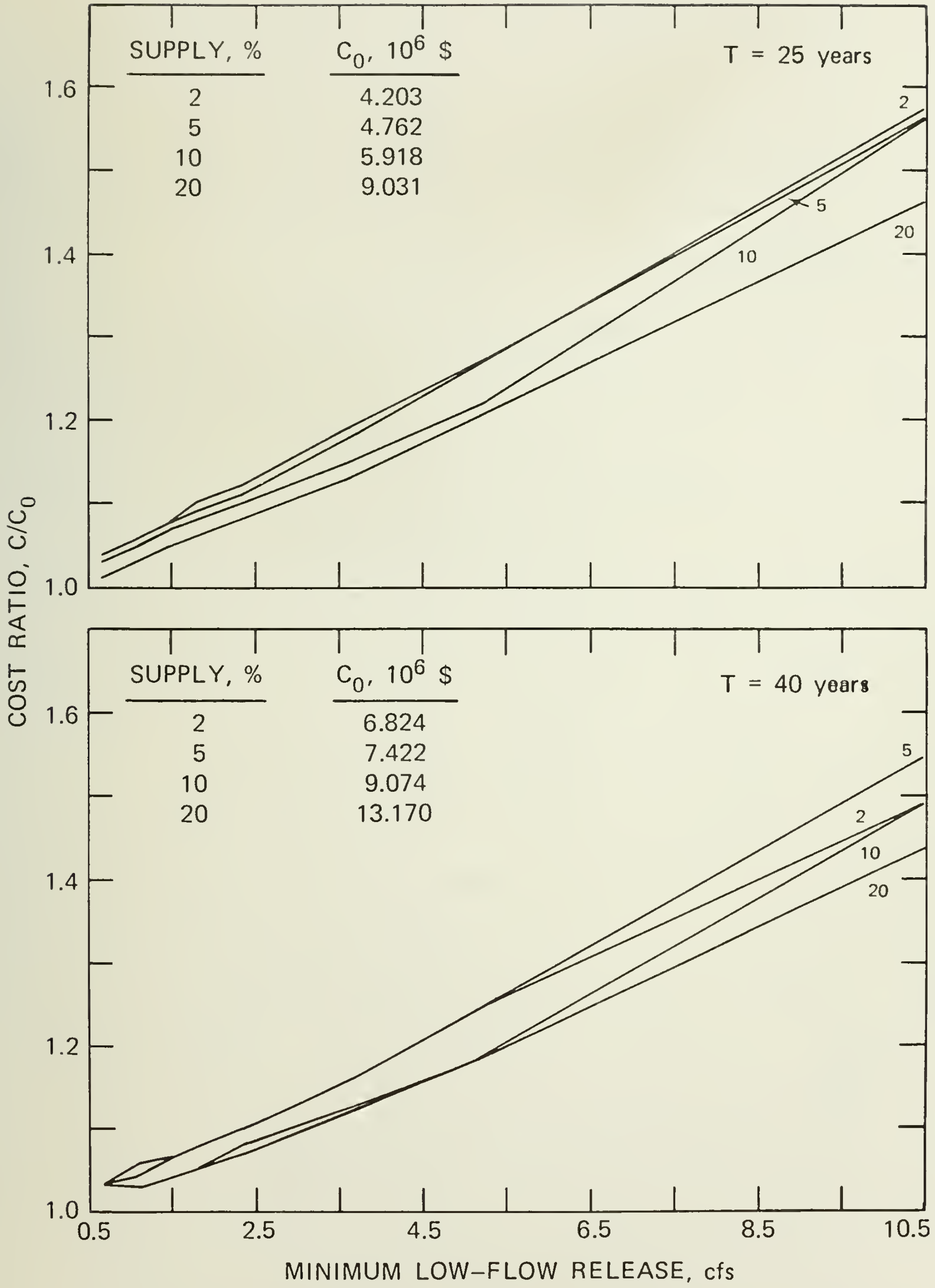


Figure 17. Cost ratio vs. low-flow release curves: Bay Creek at Nebo

The unit cost of low flow release is much higher for this basin than for the previous two basins. The reasons are smaller drainage areas and more low flow variability. The increase in unit cost with the net supply rate is attributed to high sediment potential in addition to low flow variability.

IV. *Vermilion River Basin.* The range of the low flow releases for the three gaging stations in this basin are:

No.	Stream and gaging station	Range, cfs
079	N.F. Vermilion River near Charlotte	0.49-2.16
080	Vermilion River at Pontiac	3.13-9.97
081	Vermilion River at Lowell	8.95-26.20

The lowest flow release corresponds to C5 for station 079 and to C2 for stations 080 and 081. The highest flow release corresponds to C3 for all three stations. The 7-day 10-year low flows are 0.00, 0.20, and 7.30 cfs, respectively. The $Q_{7,10}$ for Vermilion River at Pontiac would have been 2.0 cfs if the town was not withdrawing water for municipal use.

The cost ratios, CR, for the four water supply rates and range of low flow releases for the above three stations are shown in figures 18, 19, and 20. The extra capital cost per cfs of flow release for a 25-year design drought, as developed from these figures are given below for the three stations.

Station	T, years	Supply rate, %	ΔC per cfs, 10^6\$
079	25	2	0.29
		5	0.29
		10	0.24
		20	0.37
080	25	2	0.19
		5	0.19
		10	0.17

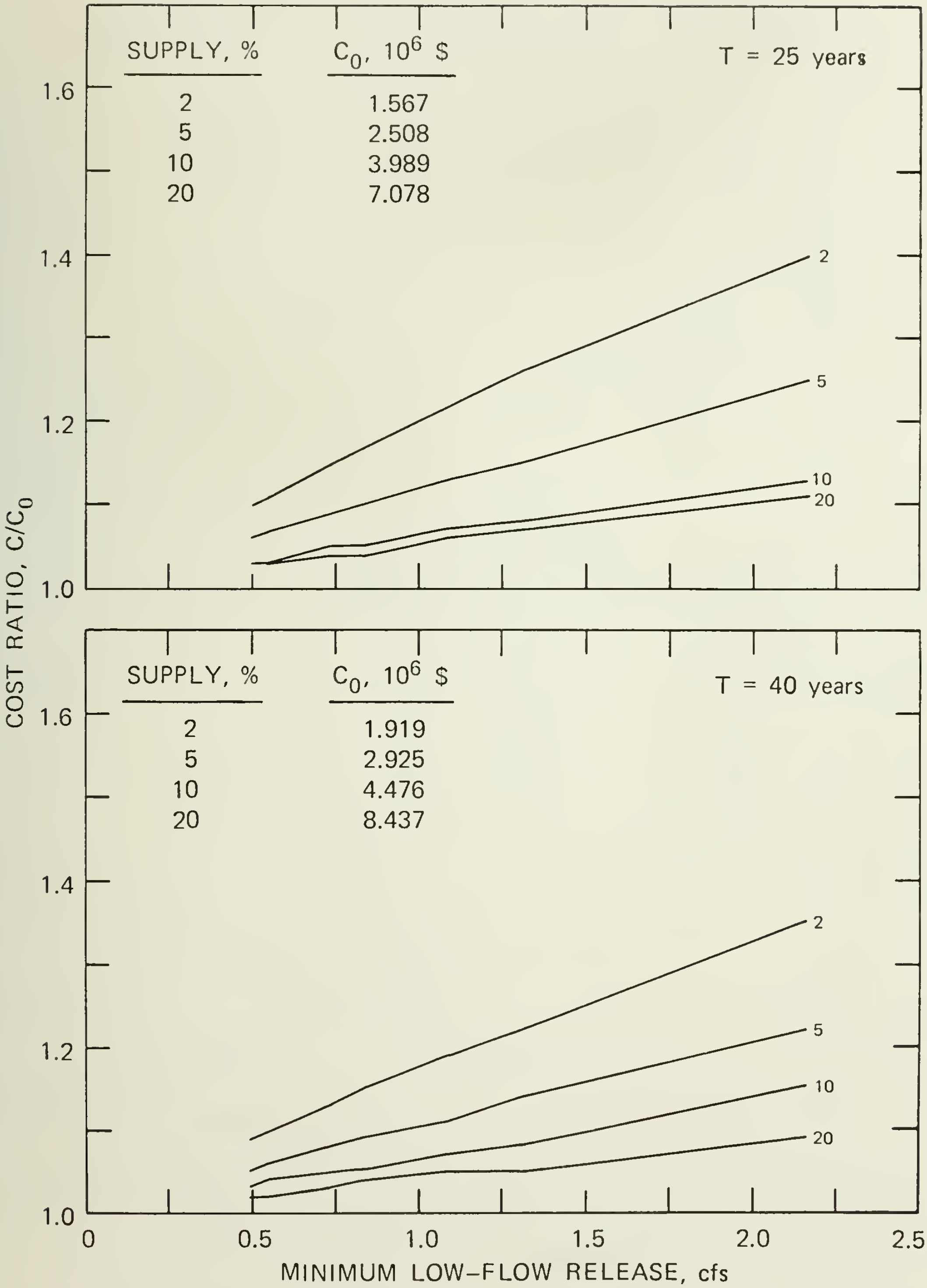


Figure 18. Cost ratio vs. low-flow release curves: N.F. Vermilion River near Charlotte

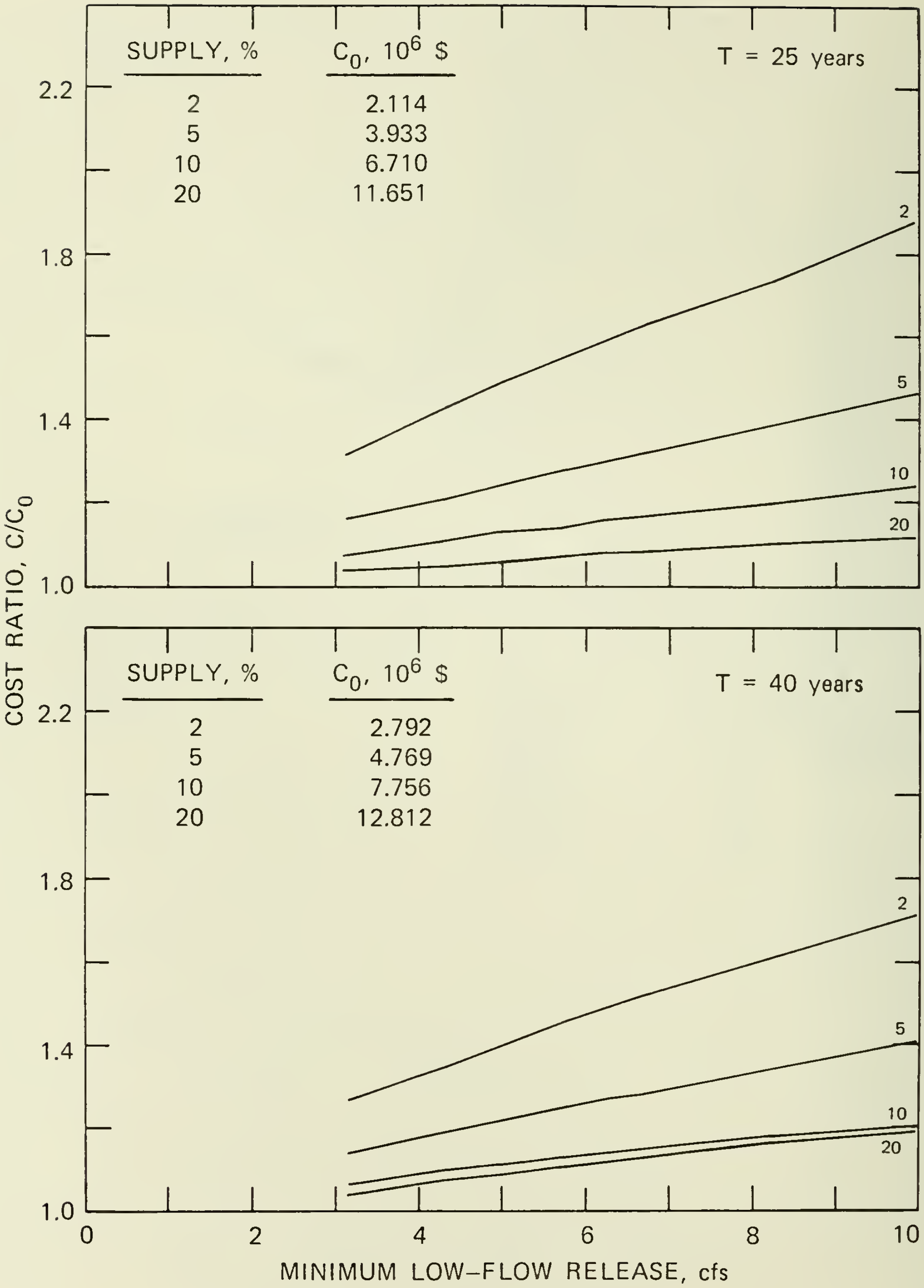


Figure 19. Cost ratio vs. low-flow release curves: Vermilion River at Pontiac

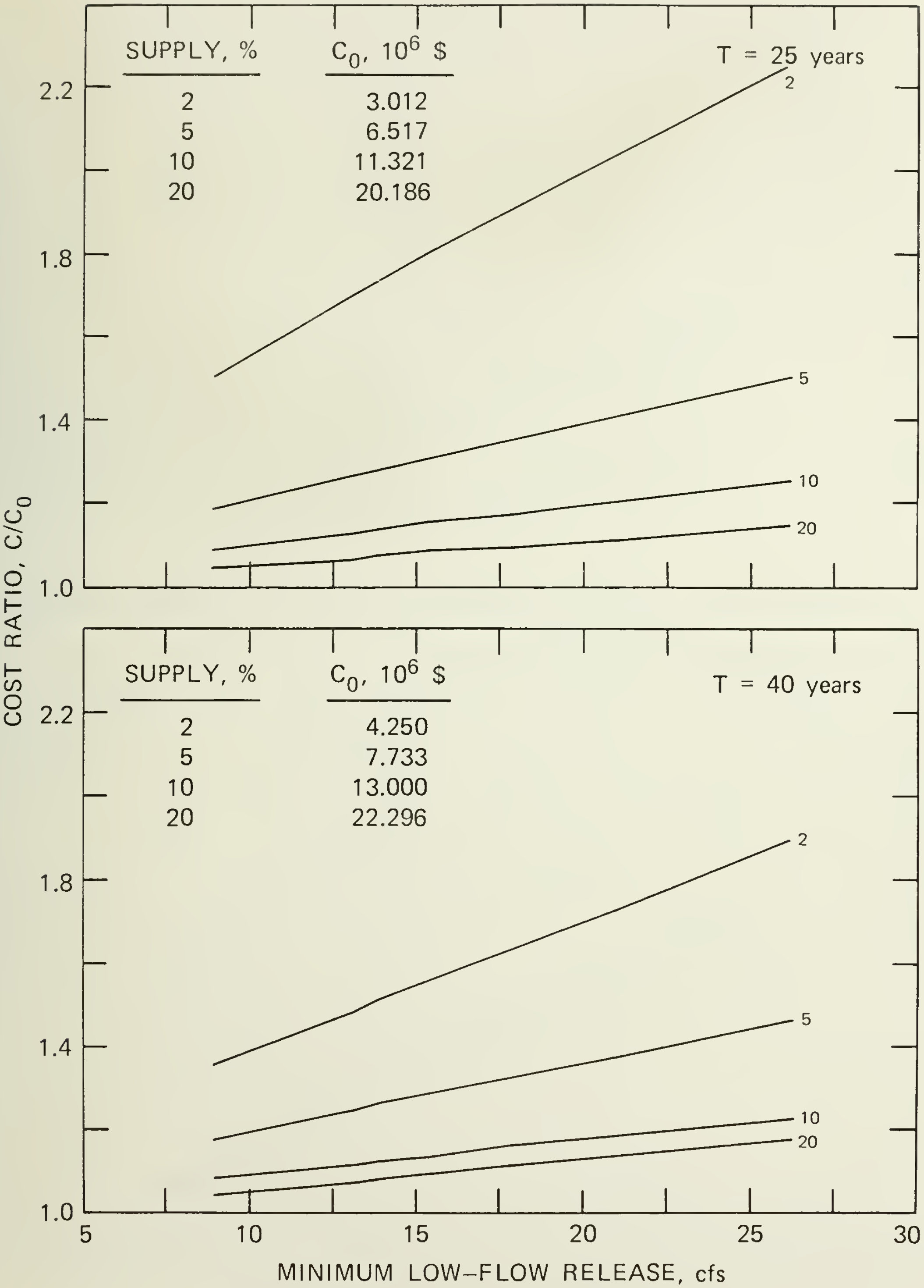


Figure 20. Cost ratio vs. low-flow release curves: Vermilion River at Lowell

Station	T, years	Supply rate, %	C per cfs, 10^6
		20	0.14
081	25	2	0.15
		5	0.13
		10	0.11
		20	0.11

The unit cost is significantly higher for station 079, with a smaller drainage area, than for stations 080 and 081 with larger drainage areas. Within a river basin, the flow duration curve for flows $\geq$ 50 percent duration becomes less steep with the increase in drainage area (Singh, 1971).

V. *South Fork Sangamon River Basin.* The range of low flow releases for the 3 gaging stations in this basin are:

No.	Stream and gaging station	Range, cfs
096	Flat Branch near Taylorville	1.02-8.17
097	S.F. Sangamon River at Kincaid	4.13-19.60
098	S.F. Sangamon River near Rochester	8.00-37.80

The lowest flow releases correspond to C5 and the highest to C3. The 7-day 10-year low flows are 0.00, 0.79, and 0.84 cfs, respectively. These are much lower than the minimum low flow releases considered above.

The cost ratios, CR, for the four water supply rates and range of low flow releases for the three stations are shown in figures 21, 22, and 23. The extra capitol costs per cfs of flow release for a 25-year design drought, as developed from these figures, are given on page 102.

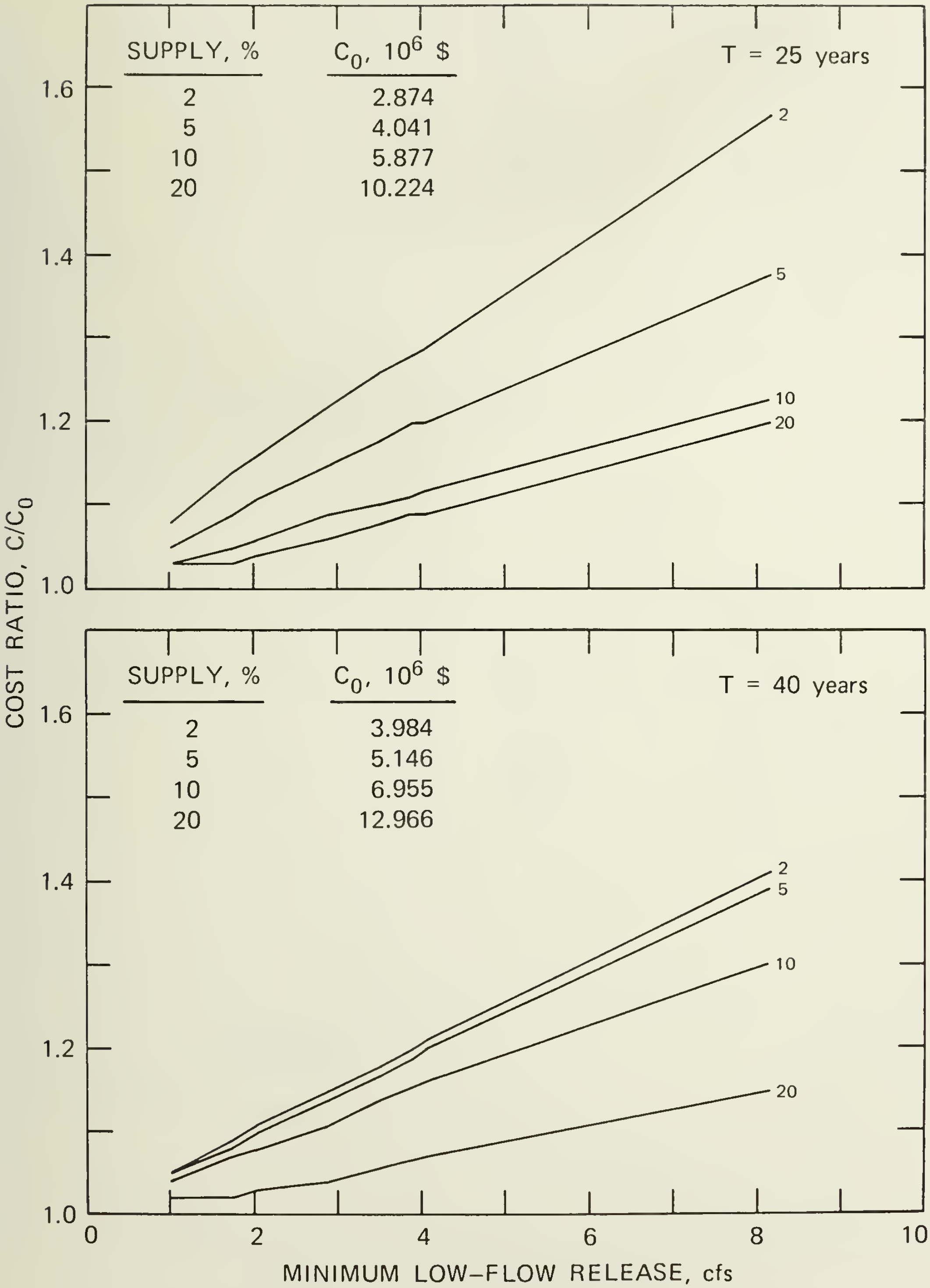


Figure 21. Cost ratio vs. low-flow release curves: Flat Branch near Taylorville

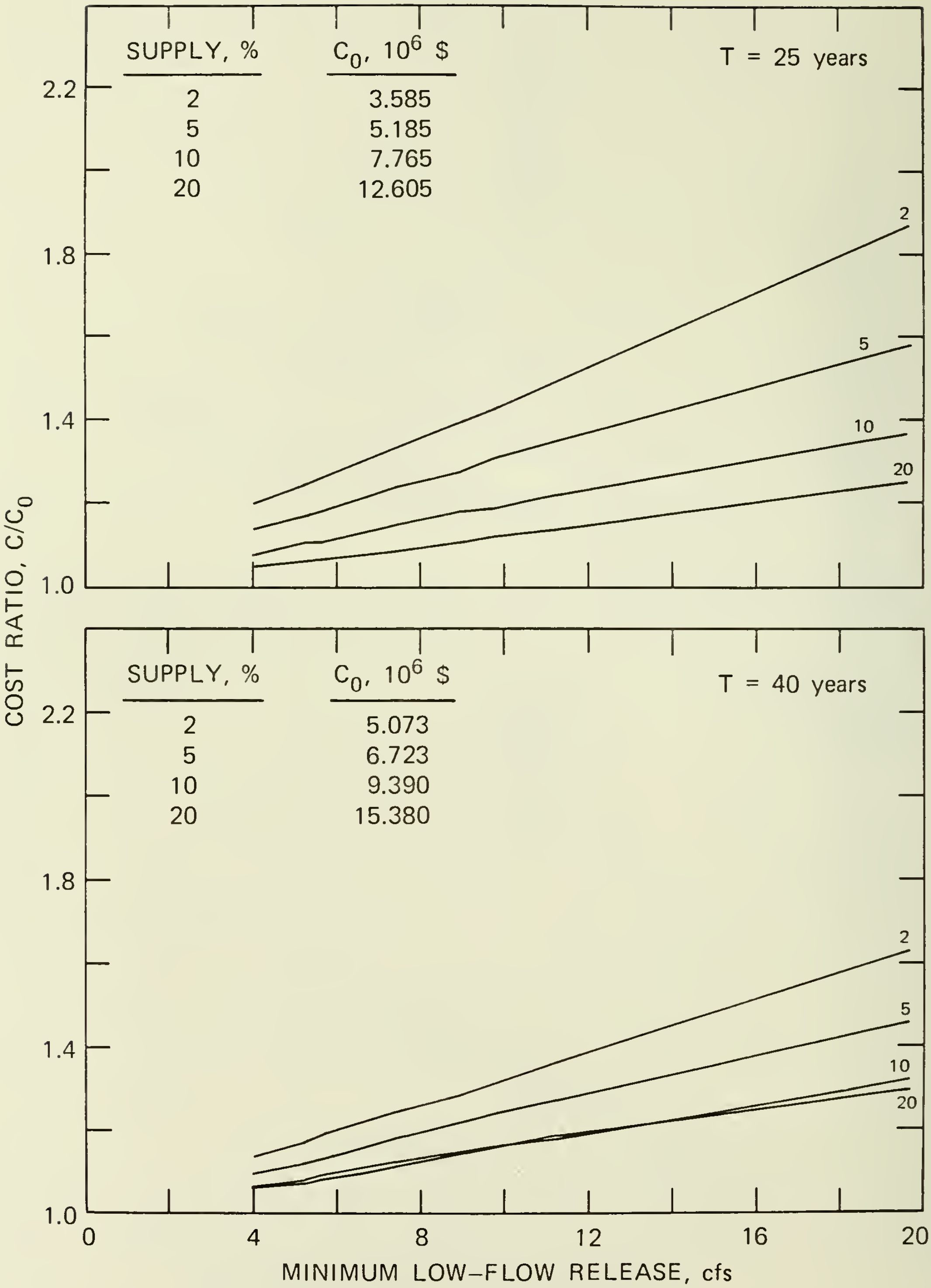


Figure 22. Cost ratio vs. low-flow release curves: S.F. Sangamon River at Kincaid

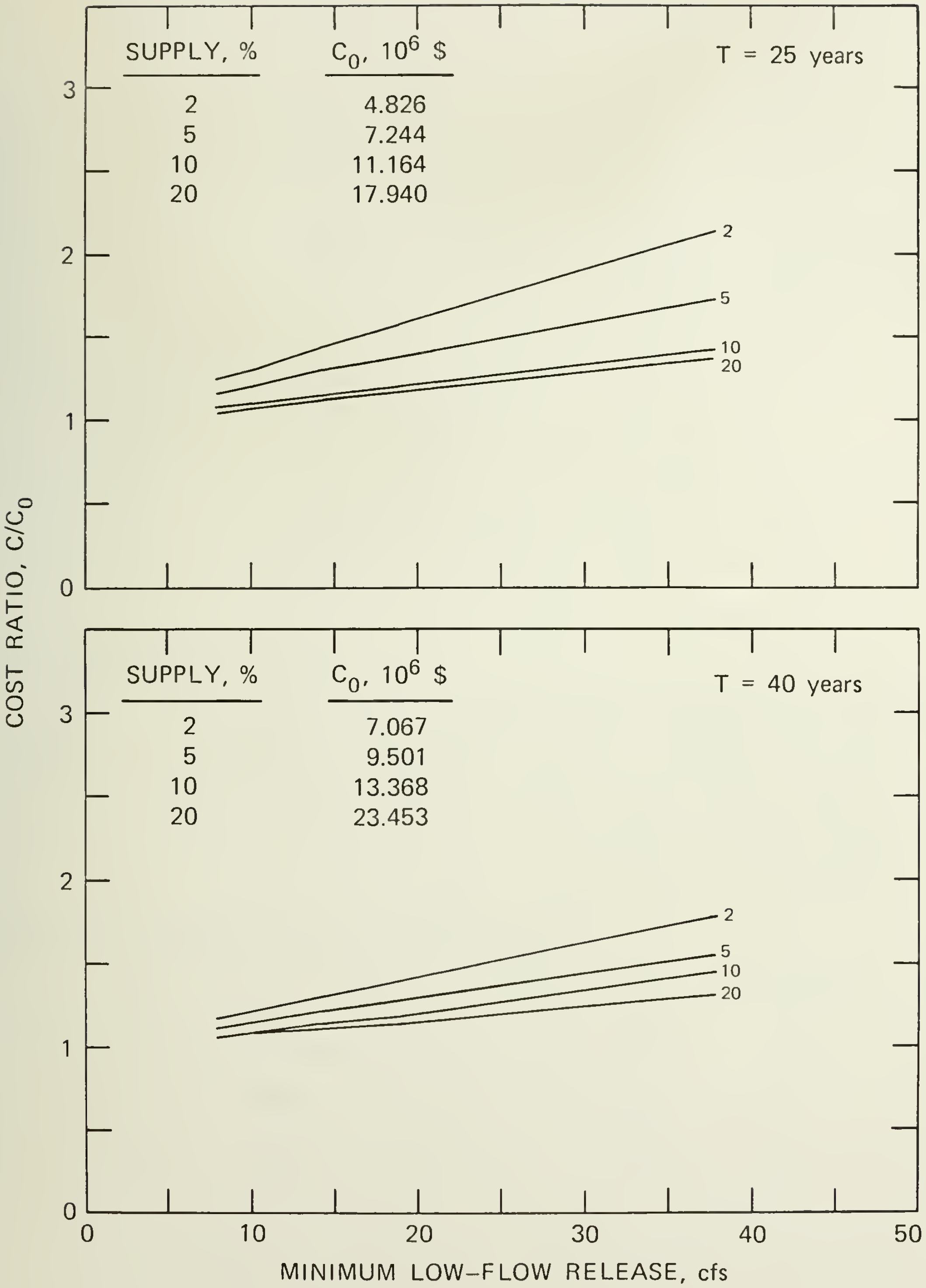


Figure 23. Cost ratio vs. low-flow release curves:
S.F. Sangamon River near Rochester

Station	T, years	Supply rate, %	ΔC per cfs, 10^6 \$
096	25	2	0.20
		5	0.19
		10	0.17
		20	0.25
097	25	2	0.16
		5	0.15
		10	0.15
		20	0.16
098	25	2	0.15
		5	0.14
		10	0.13
		20	0.18

The unit cost is significantly higher for station 096 with a 276-sq mi drainage area than for stations 097 and 098 with 562- and 867-sq mi drainage areas.

A summary of the unit costs, $\Delta C/_{cfs}$, in million dollars with a 25-year design drought is given below.

			Unit cost in million dollars with % supply rate c			
Basin	Station	D.A. sq mi	2	5	10	20
I	009	1131	0.12	0.12	0.12	0.12
	010	464	0.18	0.17	0.17	0.16
	011	3102	0.095	0.092	0.092	0.082

Basin	Station	D.A. sq mi	Unit cost in million dollars with % supply rate of 2	5	10	20
II	020	538	-	-	0.13	0.13
	021	387	-	-	0.15	0.14
	022	1099	-	-	0.11	0.11
III	039	72.7	0.27	0.27	0.32	0.44
	040	39.4	0.41	0.43	0.44	0.60
	041	161	0.23	0.26	0.31	0.40
IV	079	186	0.29	0.29	0.24	0.37
	080	579	0.19	0.19	0.17	0.14
	081	1278	0.15	0.13	0.11	0.11
V	096	276	0.20	0.19	0.17	0.25
	097	562	0.16	0.15	0.15	0.16
	098	867	0.15	0.14	0.13	0.18

Cost Versus Fish Preference

Tables 5 and 6 can be used to develop cost ratio versus flow release information as well as the unit cost of providing the flow releases from impoundments designed for various water supply rates and two drought recurrence intervals. Tables 7 and 8 yield the fish suitability values, for various flow releases, for juveniles and adults and for MIN and GM criteria. Average fish suitability indexes are developed for the nine target fish by combining their individual preferences. Thus, the cost ratios or the incremental costs can be plotted against the average fish preference or suitability for any low flow release considered. These curves can be of considerable help to the decision maker in choosing a suitable low flow release, considering the impacts on both costs and fish habitats. Such curves, developed for the five river basins, are analyzed here.

The riffles serve the purpose of reaerating the water at low flows. There is some reaeration in the pools also. However, the fish and other oxygen demand in the pools need to be balanced by reaeration in the riffle-pool sequences. Field experiments need to be conducted to determine the minimum flows required to maintain suitable DO levels for the maintenance of fish and their habitats. The information on such flows is not available at the present. The inferences drawn in the following analyses are based only on the flow velocity and depth in the riffles and pools during low flows.

I. *Little Wabash River Basin.* Cost ratio vs average fish preference curves for juvenile and adult species, applicable to riffle and pool conditions, are shown in figure 24 for a net water supply of 10 percent of mean-flow, a 25-year design drought, and b = 0.75, for the following three stations:

009	Little Wabash River below Clay City	C_o = \$13.347 million
010	Skillet Fork at Wayne City	C_o = \$ 8.419 million
011	Little Wabash River at Carmi	C_o = \$25.454 million

The information used in developing the curves is given in tables 9 through 14. The 7-day 10-year low flows are 0.00, 0.47, and 5.70 cfs, respectively.

For the Little Wabash River below Clay City, the average fish preference for the riffles is negligible for the adults and rather small for the juveniles for the low flow release range of 6.66 to 38.50 cfs. In the pools, the juvenile fish preference increases from 0.62 to 0.66 with MIN and 0.70 to 0.73 with GM as the flow increases from 6.66 to 38.5 cfs. The preference for the adults increases from 0.24 to 0.57 with MIN and 0.41 to 0.66 with GM. The cost preference curve steepens beyond $^{C}/_{C_o}$ = 1.15 which corresponds to a flow of 15 cfs.

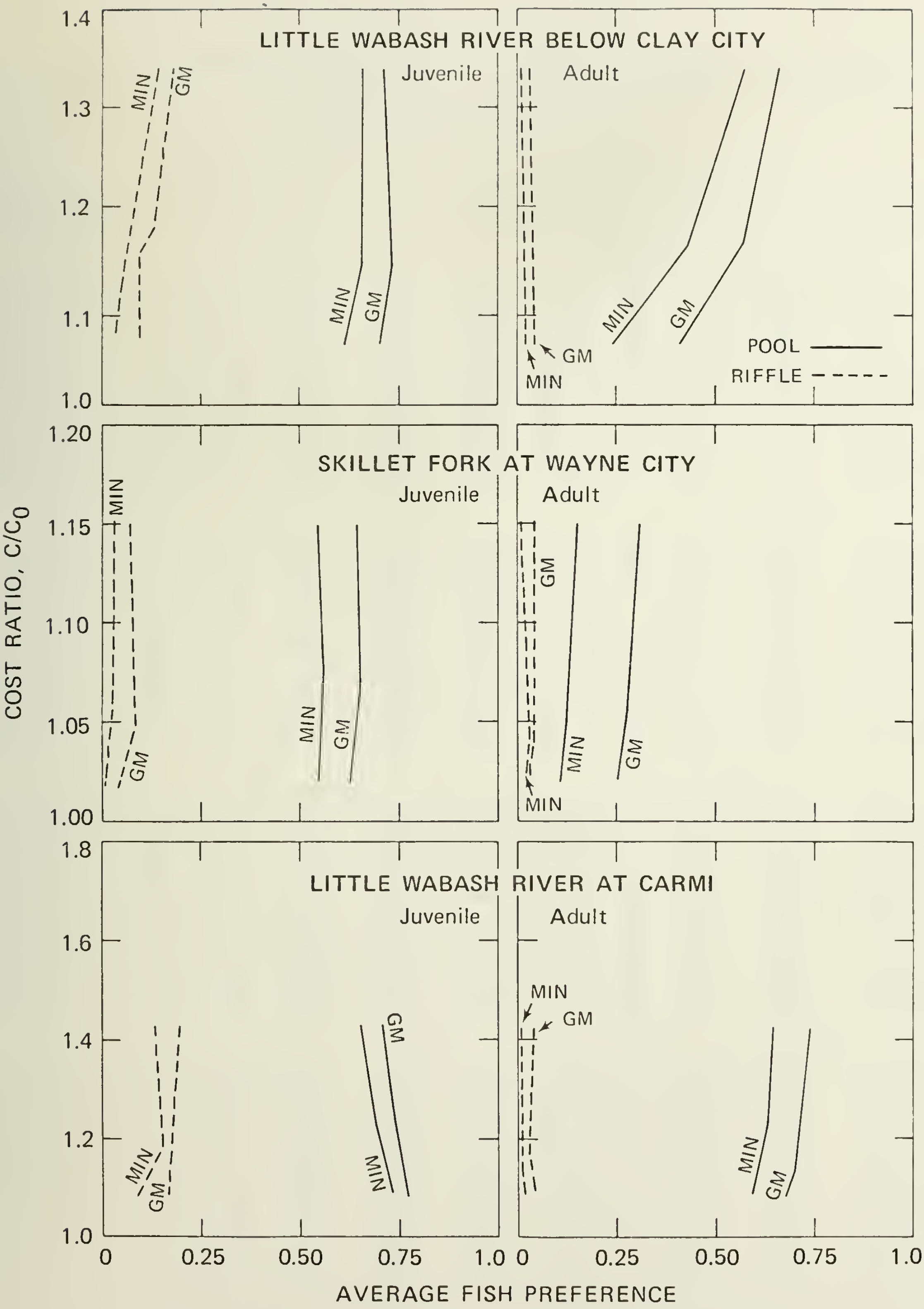


Figure 24. Cost ratio vs. average fish preference. Little Wabash River Basin

Table 9. Fish Suitability (MIN Criterion) for the Range of Low Flow Releases

Station No. 9 ; USGS No. 03379500 ; Little Wabash River below Clay City
D.A. 1131 Sq Mi ; Mean Flow 881 cfs ; Q(7,10) 0.47 cfs

Q		Suitability for Fish Number										
cfs	No.	1	2	3	4	5	6	7	8	9	avg	C/C_o
A. Juvenile (riffle condition)												
6.66	5	.00	.07	.00	.00	.09	.14	.00	.00	.00	.03	1.06
7.75	2	.00	.06	.00	.00	.10	.15	.00	.00	.00	.03	1.07
9.20	7	.00	.04	.00	.00	.12	.18	.00	.00	.00	.04	1.09
10.00	6	.00	.04	.00	.00	.13	.19	.00	.00	.00	.04	1.10
14.90	8	.00	.03	.00	.00	.20	.26	.00	.00	.00	.05	1.14
15.50	1	.00	.03	.00	.00	.21	.27	.00	.00	.00	.06	1.15
19.30	4	.00	.02	.00	.00	.25	.33	.00	.00	.12	.08	1.18
38.50	3	.00	.01	.00	.02	.28	.34	.00	.00	.62	.14	1.34
B. Adult (riffle condition)												
6.66	5	.00	.16	.00	.00	.00	.00	.00	.00	.00	.02	1.06
7.75	2	.00	.15	.00	.00	.00	.00	.00	.00	.00	.02	1.07
9.20	7	.00	.14	.00	.00	.00	.00	.00	.00	.00	.02	1.09
10.00	6	.00	.14	.00	.00	.00	.00	.00	.00	.00	.02	1.10
14.90	8	.00	.11	.00	.00	.00	.00	.00	.00	.00	.01	1.14
15.50	1	.00	.11	.00	.00	.00	.00	.00	.00	.00	.01	1.15
19.30	4	.00	.10	.00	.00	.00	.00	.00	.00	.00	.01	1.18
38.50	3	.01	.07	.00	.00	.00	.01	.00	.00	.00	.01	1.34
C. Juvenile (pool condition)												
6.66	5	.86	.00	.21	.07	.99	1.00	.71	.72	1.00	.62	1.06
7.75	2	.79	.00	.25	.07	.99	1.00	.73	.73	1.00	.62	1.07
9.20	7	.72	.00	.38	.07	.99	1.00	.75	.75	1.00	.63	1.09
10.00	6	.67	.00	.47	.08	.99	1.00	.77	.75	1.00	.64	1.10
14.90	8	.47	.00	.81	.08	.98	1.00	.82	.79	1.00	.66	1.14
15.50	1	.45	.00	.84	.08	.98	1.00	.82	.79	1.00	.66	1.15
19.30	4	.34	.00	.90	.08	.98	1.00	.86	.81	1.00	.66	1.18
38.50	3	.12	.00	.98	.08	.93	.99	.95	.88	.99	.66	1.34
D. Adult (pool condition)												
6.66	5	.62	.00	.26	.16	.19	.49	.09	.00	.36	.24	1.06
7.75	2	.65	.00	.28	.16	.20	.50	.15	.00	.40	.26	1.07
9.20	7	.68	.00	.31	.17	.20	.52	.28	.00	.45	.29	1.09
10.00	6	.70	.00	.33	.17	.21	.53	.38	.00	.49	.31	1.10
14.90	8	.79	.00	.47	.18	.23	.58	.66	.02	.63	.40	1.14
15.50	1	.80	.00	.48	.18	.23	.59	.67	.02	.64	.40	1.15
19.30	4	.83	.00	.63	.19	.24	.62	.77	.05	.69	.45	1.18
38.50	3	.88	.00	.97	.23	.29	.75	.95	.17	.85	.57	1.34

Note: Q = Minimum flow release
C/C_o = Ratio of reservoir cost with Q to that with Q=0 (T=25 years, net water supply equals 10% of mean flow)

Table 10. Fish Suitability (GM Criterion) for the Range of Low Flow Releases

Station No. 9 ; USGS No. 03379500 ; Little Wabash River below Clay City
D.A. 1131 Sq Mi : Mean Flow 881 cfs ; Q(7,10) 0.47 cfs

Q		Suitability for Fish Number										
cfs	No.	1	2	3	4	5	6	7	8	9	avg	C/C_o
A. Juvenile (riffle condition)												
6.66	5	.00	.21	.00	.00	.25	.31	.00	.00	.00	.09	1.06
7.75	2	.00	.20	.00	.00	.26	.31	.00	.00	.00	.09	1.07
9.20	7	.00	.18	.00	.00	.26	.33	.00	.00	.00	.09	1.09
10.00	6	.00	.19	.00	.00	.28	.34	.00	.00	.00	.09	1.10
14.90	8	.00	.17	.00	.00	.31	.37	.00	.00	.00	.09	1.14
15.50	1	.00	.17	.00	.00	.31	.37	.00	.00	.00	.09	1.15
19.30	4	.00	.15	.00	.00	.32	.39	.00	.00	.31	.13	1.18
38.50	3	.00	.03	.00	.05	.40	.46	.00	.00	.70	.18	1.34
B. Adult (riffle condition)												
6.66	5	.00	.40	.00	.00	.00	.00	.00	.00	.00	.04	1.06
7.75	2	.00	.39	.00	.00	.00	.00	.00	.00	.00	.04	1.07
9.20	7	.00	.38	.00	.00	.00	.00	.00	.00	.00	.04	1.09
10.00	6	.00	.37	.00	.00	.00	.00	.00	.00	.00	.04	1.10
14.90	8	.00	.33	.00	.00	.00	.00	.00	.00	.00	.04	1.14
15.50	1	.00	.33	.00	.00	.00	.00	.00	.00	.00	.04	1.15
19.30	4	.00	.31	.00	.00	.00	.00	.00	.00	.00	.03	1.18
38.50	3	.03	.18	.00	.00	.04	.09	.00	.00	.00	.04	1.34
C. Juvenile (pool condition)												
6.66	5	.93	.00	.46	.20	1.00	1.00	.85	.85	1.00	.70	1.06
7.75	2	.89	.00	.50	.20	1.00	1.00	.86	.86	1.00	.70	1.07
9.20	7	.85	.00	.61	.20	1.00	1.00	.87	.86	1.00	.71	1.09
10.00	6	.82	.00	.68	.20	1.00	1.00	.88	.87	1.00	.72	1.10
14.90	8	.69	.00	.90	.21	.99	1.00	.90	.89	1.00	.73	1.14
15.50	1	.67	.00	.92	.21	.99	1.00	.91	.89	1.00	.73	1.15
19.30	4	.58	.00	.95	.22	.99	1.00	.93	.90	1.00	.73	1.18
38.50	3	.35	.00	.98	.23	.97	1.00	.97	.94	.99	.71	1.34
D. Adult (pool condition)												
6.66	5	.79	.02	.51	.40	.44	.60	.29	.00	.60	.41	1.06
7.75	2	.81	.00	.53	.40	.44	.61	.39	.00	.63	.42	1.07
9.20	7	.82	.00	.55	.41	.45	.62	.53	.00	.67	.45	1.09
10.00	6	.84	.00	.57	.41	.46	.63	.61	.00	.70	.47	1.10
14.90	8	.89	.00	.68	.42	.48	.66	.81	.13	.79	.54	1.14
15.50	1	.89	.00	.69	.42	.48	.66	.82	.15	.80	.55	1.15
19.30	4	.91	.00	.79	.43	.49	.68	.88	.23	.83	.58	1.18
38.50	3	.92	.00	.98	.48	.53	.75	.97	.42	.91	.66	1.34

Note: Q = Minimum flow release
C/C_o = Ratio of reservoir cost with Q to that with Q=0 (T=25 years, net water supply equals 10% of mean flow)

Table 11. Fish Suitability (MIN Criterion) for the Range of Low Flow Releases

Station No. 10 ; USGS No. 03380500 ; Skillet Fork at Wayne City
D.A. 464 Sq Mi ; Mean Flow 392 cfs ; Q(7,10) 0.00 cfs

Q		Suitability for Fish Number										
cfs	No.	1	2	3	4	5	6	7	8	9	avg	C/C_o
A. Juvenile (riffle condition)												
.74	5	.00	.00	.00	.00	.02	.05	.00	.00	.00	.01	1.02
.92	2	.00	.00	.00	.00	.02	.05	.00	.00	.00	.01	1.02
1.21	6	.00	.00	.00	.00	.03	.06	.00	.00	.00	.01	1.03
1.27	7	.00	.00	.00	.00	.03	.06	.00	.00	.00	.01	1.03
1.84	1	.00	.08	.00	.00	.04	.08	.00	.00	.00	.02	1.04
2.17	8	.00	.13	.00	.00	.05	.08	.00	.00	.00	.03	1.04
3.89	4	.00	.10	.00	.00	.07	.11	.00	.00	.00	.03	1.08
7.78	3	.00	.03	.00	.00	.10	.15	.00	.00	.00	.03	1.15
B. Adult (riffle condition)												
.74	5	.00	.18	.00	.00	.00	.00	.00	.00	.00	.02	1.02
.92	2	.00	.20	.00	.00	.00	.00	.00	.00	.00	.02	1.02
1.21	6	.00	.28	.00	.00	.00	.00	.00	.00	.00	.03	1.03
1.27	7	.00	.28	.00	.00	.00	.00	.00	.00	.00	.03	1.03
1.84	1	.00	.27	.00	.00	.00	.00	.00	.00	.00	.03	1.04
2.17	8	.00	.25	.00	.00	.00	.00	.00	.00	.00	.03	1.04
3.89	4	.00	.19	.00	.00	.00	.00	.00	.00	.00	.02	1.08
7.78	3	.00	.12	.00	.00	.00	.00	.00	.00	.00	.01	1.15
C. Juvenile (pool condition)												
.74	5	1.00	.00	.04	.07	1.00	1.00	.32	.47	1.00	.54	1.02
.92	2	1.00	.00	.04	.07	1.00	1.00	.33	.48	1.00	.55	1.02
1.21	6	1.00	.00	.05	.07	1.00	1.00	.35	.50	1.00	.55	1.03
1.27	7	1.00	.00	.05	.07	1.00	1.00	.35	.50	1.00	.55	1.03
1.84	1	.99	.00	.05	.07	1.00	1.00	.38	.52	1.00	.56	1.04
2.17	8	.98	.00	.05	.07	1.00	1.00	.39	.53	1.00	.56	1.04
3.89	4	.92	.00	.06	.07	.99	1.00	.44	.56	1.00	.56	1.08
7.78	3	.61	.00	.09	.08	.99	1.00	.53	.61	1.00	.55	1.15
D. Adult (pool condition)												
.74	5	.28	.01	.10	.11	.11	.29	.00	.00	.06	.11	1.02
.92	2	.29	.01	.10	.11	.11	.30	.00	.00	.07	.11	1.02
1.21	6	.30	.01	.11	.11	.11	.31	.00	.00	.07	.11	1.03
1.27	7	.30	.01	.11	.11	.11	.31	.00	.00	.07	.11	1.03
1.84	1	.32	.01	.12	.11	.12	.32	.00	.00	.08	.12	1.04
2.17	8	.33	.01	.12	.11	.12	.33	.00	.00	.09	.12	1.04
3.89	4	.36	.01	.14	.12	.13	.35	.00	.00	.10	.13	1.08
7.78	3	.41	.01	.16	.13	.15	.38	.00	.00	.15	.15	1.15

Note: Q = Minimum flow release
C/C_o = Ratio of reservoir cost with Q to that with Q=0 (T=25 years, net water supply equals 10% of mean flow)

Table 12. Fish Suitability (GM Criterion) for the Range of Low Flow Releases

Station No. 10 ; USGS No. 03380500 ; Skillet Fork at Wayne City
D.A. 464 Sq Mi ; Mean Flow 392 cfs ; Q(7,10) 0.00 cfs

Q		Suitability for Fish Number										
cfs	No.	1	2	3	4	5	6	7	8	9	avg	C/C_o
A. Juvenile (riffle condition)												
.74	5	.00	.00	.00	.00	.14	.22	.00	.00	.00	.04	1.02
.92	2	.00	.00	.00	.00	.15	.23	.00	.00	.00	.04	1.02
1.21	6	.00	.00	.00	.00	.17	.25	.00	.00	.00	.05	1.03
1.27	7	.00	.00	.00	.00	.17	.25	.00	.00	.00	.05	1.03
1.84	1	.00	.20	.00	.00	.19	.27	.00	.00	.00	.07	1.04
2.17	8	.00	.22	.00	.00	.20	.28	.00	.00	.00	.08	1.04
3.89	4	.00	.17	.00	.00	.22	.29	.00	.00	.00	.08	1.08
7.78	3	.00	.15	.00	.00	.23	.28	.00	.00	.00	.07	1.15
B. Adult (riffle condition)												
.74	5	.00	.26	.00	.00	.00	.00	.00	.00	.00	.03	1.02
.92	2	.00	.27	.00	.00	.00	.00	.00	.00	.00	.03	1.02
1.21	6	.00	.29	.00	.00	.00	.00	.00	.00	.00	.03	1.03
1.27	7	.00	.29	.00	.00	.00	.00	.00	.00	.00	.03	1.03
1.84	1	.00	.31	.00	.00	.00	.00	.00	.00	.00	.03	1.04
2.17	8	.00	.32	.00	.00	.00	.00	.00	.00	.00	.04	1.04
3.89	4	.00	.39	.00	.00	.00	.00	.00	.00	.00	.04	1.08
7.78	3	.00	.34	.00	.00	.00	.00	.00	.00	.00	.04	1.15
C. Juvenile (pool condition)												
.74	5	1.00	.00	.20	.17	1.00	1.00	.56	.69	1.00	.62	1.02
.92	2	1.00	.00	.21	.17	1.00	1.00	.57	.69	1.00	.63	1.02
1.21	6	1.00	.00	.22	.17	1.00	1.00	.59	.70	1.00	.63	1.03
1.27	7	1.00	.00	.22	.17	1.00	1.00	.59	.70	1.00	.63	1.03
1.84	1	.99	.00	.23	.18	1.00	1.00	.61	.72	1.00	.64	1.04
2.17	8	.99	.00	.23	.18	1.00	1.00	.63	.73	1.00	.64	1.04
3.89	4	.96	.00	.25	.18	1.00	1.00	.67	.75	1.00	.65	1.08
7.78	3	.78	.00	.30	.19	1.00	1.00	.72	.78	1.00	.64	1.15
D. Adult (pool condition)												
.74	5	.53	.11	.32	.33	.33	.46	.00	.00	.25	.26	1.02
.92	2	.54	.11	.32	.33	.33	.47	.00	.00	.26	.26	1.02
1.21	6	.55	.10	.33	.33	.34	.48	.00	.00	.27	.27	1.03
1.27	7	.55	.10	.33	.33	.34	.48	.00	.00	.27	.27	1.03
1.84	1	.56	.10	.35	.34	.34	.48	.00	.00	.29	.27	1.04
2.17	8	.57	.09	.35	.34	.34	.49	.00	.00	.30	.28	1.04
3.89	4	.60	.09	.37	.35	.36	.51	.00	.00	.32	.29	1.08
7.78	3	.64	.07	.40	.36	.38	.53	.00	.00	.39	.31	1.15

Note: Q = Minimum flow release
C/C_o = Ratio of reservoir cost with Q to that with Q=0 (T=25 years, net water supply equals 10% of mean flow)

Table 13. Fish Suitability (MIN Criterion) for the Range of Low Flow Releases

Station No. 11 : USGS No. 03381500 ; Little Wabash River at Carmi
D.A. 3102 Sq Mi ; Mean Flow 2521 cfs ; Q(7,10) 5.70 cfs

Q		Suitability for Fish Number										
cfs	No.	1	2	3	4	5	6	7	8	9	avg	C/C_o
A. Juvenile (riffle condition)												
24.00	5	.00	.08	.00	.00	.25	.33	.00	.00	.12	.09	1.09
29.93	7	.00	.05	.00	.00	.28	.37	.00	.00	.21	.10	1.11
32.00	2	.00	.04	.00	.00	.30	.39	.00	.00	.25	.11	1.12
36.00	6	.00	.04	.00	.00	.32	.40	.00	.00	.29	.12	1.13
49.76	8	.00	.02	.00	.00	.39	.47	.00	.00	.46	.15	1.18
61.50	4	.00	.02	.00	.01	.35	.41	.00	.00	.57	.15	1.22
63.90	1	.00	.01	.00	.01	.33	.40	.00	.00	.58	.15	1.23
123.00	3	.00	.00	.00	.08	.18	.21	.00	.00	.69	.13	1.43
B. Adult (riffle condition)												
24.00	5	.00	.17	.00	.00	.00	.00	.00	.00	.00	.02	1.09
29.93	7	.00	.15	.00	.00	.00	.00	.00	.00	.00	.02	1.11
32.00	2	.00	.14	.00	.00	.00	.00	.00	.00	.00	.02	1.12
36.00	6	.00	.13	.00	.00	.00	.00	.00	.00	.00	.01	1.13
49.76	8	.01	.09	.00	.00	.00	.00	.00	.00	.00	.01	1.18
61.50	4	.01	.08	.00	.00	.00	.00	.00	.00	.00	.01	1.22
63.90	1	.01	.08	.00	.00	.00	.00	.00	.00	.00	.01	1.23
123.00	3	.03	.03	.00	.00	.02	.03	.00	.00	.00	.01	1.43
C. Juvenile (pool condition)												
24.00	5	.69	.00	.98	.08	.99	1.00	.96	.89	1.00	.73	1.09
29.93	7	.56	.00	.98	.08	.99	1.00	.97	.91	1.00	.72	1.11
32.00	2	.53	.00	.99	.08	.99	1.00	.98	.91	1.00	.72	1.12
36.00	6	.48	.00	.99	.08	.98	1.00	.98	.91	1.00	.71	1.13
49.76	8	.30	.00	1.00	.08	.97	1.00	1.00	.94	1.00	.70	1.18
61.50	4	.24	.00	1.00	.08	.96	1.00	1.00	.95	1.00	.69	1.22
63.90	1	.21	.00	1.00	.08	.96	1.00	1.00	.95	1.00	.69	1.23
123.00	3	.06	.00	.97	.08	.88	.94	.98	.97	.97	.65	1.43
D. Adult (pool condition)												
24.00	5	.98	.00	.98	.24	.30	.74	.96	.19	.88	.59	1.09
29.93	7	.99	.00	.98	.25	.31	.74	.98	.21	.90	.60	1.11
32.00	2	.99	.00	.99	.26	.31	.74	.98	.22	.91	.60	1.12
36.00	6	1.00	.00	.99	.27	.32	.74	.99	.23	.92	.61	1.13
49.76	8	1.00	.00	1.00	.29	.33	.75	1.00	.27	.95	.62	1.18
61.50	4	.97	.00	1.00	.34	.35	.75	1.00	.30	.97	.63	1.22
63.90	1	.96	.00	1.00	.35	.35	.75	1.00	.30	.97	.63	1.23
123.00	3	.72	.00	.96	.56	.39	.77	1.00	.41	.92	.64	1.43

Note: Q = Minimum flow release
C/C_o = Ratio of reservoir cost with Q to that with Q=0 (T=25 years, net water supply equals 10% of mean flow)

Table 14. Fish Suitability (GM Criterion) for the Range of Low Flow Releases

Station No. 11 ; USGS No. 03381500 ; Little Wabash River at Carmi
D.A. 3102 Sq Mi ; Mean Flow 2521 cfs ; Q(7,10) 5.70 cfs

Q		Suitability for Fish Number										
cfs	No.	1	2	3	4	5	6	7	8	9	avg	C/C_o
A. Juvenile (riffle condition)												
24.00	5	.00	.26	.00	.00	.41	.48	.00	.00	.33	.16	1.09
29.93	7	.00	.18	.00	.00	.42	.48	.00	.00	.44	.17	1.11
32.00	2	.00	.12	.00	.00	.42	.48	.00	.00	.47	.17	1.12
36.00	6	.00	.10	.00	.00	.41	.48	.00	.00	.51	.17	1.13
49.76	8	.00	.07	.00	.00	.40	.47	.00	.00	.63	.17	1.18
61.50	4	.00	.05	.00	.03	.41	.47	.00	.00	.68	.18	1.22
63.90	1	.00	.05	.00	.04	.41	.47	.00	.00	.69	.18	1.23
123.00	3	.00	.00	.00	.14	.40	.45	.00	.00	.74	.19	1.43
B. Adult (riffle condition)												
24.00	5	.00	.41	.00	.00	.00	.00	.00	.00	.00	.05	1.09
29.93	7	.02	.38	.00	.00	.00	.00	.00	.00	.00	.04	1.11
32.00	2	.02	.37	.00	.00	.00	.00	.00	.00	.00	.04	1.12
36.00	6	.03	.35	.00	.00	.00	.00	.00	.00	.00	.04	1.13
49.76	8	.03	.29	.00	.00	.00	.00	.00	.00	.00	.03	1.18
61.50	4	.03	.26	.00	.00	.03	.05	.00	.00	.00	.04	1.22
63.90	1	.03	.26	.00	.00	.03	.06	.00	.00	.00	.04	1.23
123.00	3	.04	.09	.00	.00	.07	.18	.00	.00	.00	.04	1.43
C. Juvenile (pool condition)												
24.00	5	.83	.00	.99	.22	1.00	1.00	.98	.95	1.00	.77	1.09
29.93	7	.75	.00	.99	.23	1.00	1.00	.99	.95	1.00	.77	1.11
32.00	2	.73	.00	.99	.23	.99	1.00	.99	.95	1.00	.76	1.12
36.00	6	.69	.00	.99	.23	.99	1.00	.99	.96	1.00	.76	1.13
49.76	8	.54	.00	1.00	.24	.99	1.00	1.00	.97	1.00	.75	1.18
61.50	4	.47	.00	1.00	.24	.98	1.00	1.00	.97	1.00	.74	1.22
63.90	1	.45	.00	1.00	.24	.98	1.00	1.00	.97	1.00	.74	1.23
123.00	3	.23	.00	.99	.27	.94	.97	.99	.99	.97	.71	1.43
D. Adult (pool condition)												
24.00	5	.99	.00	.99	.49	.55	.76	.98	.44	.94	.68	1.09
29.93	7	.99	.00	.99	.50	.55	.77	.99	.46	.95	.69	1.11
32.00	2	1.00	.00	.99	.51	.56	.78	.99	.47	.95	.69	1.12
36.00	6	1.00	.00	.99	.52	.56	.78	.99	.48	.96	.70	1.13
49.76	8	1.00	.00	1.00	.54	.58	.80	1.00	.52	.98	.71	1.18
61.50	4	.99	.00	1.00	.58	.58	.82	1.00	.55	.98	.72	1.22
63.90	1	.98	.00	1.00	.59	.59	.82	1.00	.55	.99	.72	1.23
123.00	3	.85	.00	.98	.73	.60	.86	1.00	.64	.96	.74	1.43

Note: Q = Minimum flow release
C/C_o = Ratio of reservoir cost with Q to that with Q=0 (T=25 years, net water supply equals 10% of mean flow)

In the case of Skillet Fork at Wayne City, the average fish preference for the riffles is very small, both for the juveniles and adults, for the low flow range of 0.74 to 7.78 cfs. In the pools, the juvenile fish preference is about 0.55 with MIN and 0.64 with GM for the entire low flow range considered. The preference for the adults increases from 0.11 to 0.15 with MIN and 0.26 to 0.31 with GM as flow increases from 0.74 to 7.78 cfs (the extra capital cost increases from $0.13 to 1.13 million). Probably much higher flow releases than 7.78 cfs will be needed to increase the adult fish preferences considerably.

For the Little Wabash River at Carmi, the average fish preference for the riffles is negligible for the adults and varies from 0.09 to 0.13 with MIN and 0.16 to 0.19 with GM for the juveniles, for the low flow range of 24 to 123 cfs. In the pools, the juvenile fish preferences decrease from 0.73 to 0.65 with MIN and 0.77 to 0.71 with GM as the flow increases from 24 to 123 cfs. The preference for adult fish increases from 0.59 to 0.64 with MIN and from 0.68 to 0.74 with GM with increase in flow. The increase in preference is rather small. The fish preferences need to be calculated for flows less than 24 cfs to determine if a lesser flow release may be appropriate. The 7-day 10-year low flow is 5.7 cfs.

A summary of the fish preferences at the two ends of low flow range (and an intermediate value for station 009) is given in table 15. The preference of the bluntnose for the low flow ranges analyzed is very small. The decision on a suitable low flow release will be governed by the relative weight for the target species, their preferences, and extra capital costs, ΔC.

II. *Kishwaukee River Basin.* Cost ratio vs average fish preference curves for juvenile and adult species, applicable to riffle and pool conditions, are

TABLE 15. Costs and Fish Preferences: Little Wabash River Basin (Pool Condition)

	Q	ΔC			Fish number* with preference				
No.	cfs	10^6 $	†	Crit	<0.1	0.10-0.24	0.25-0.49	0.50-0.74	0.75-1.00
009	6.66	0.85	J	MIN	2,4	3		7,8	1,5,6,9
				GM	2	4	3		1,5-9
			A	MIN	2,7,8	4,5	3,6,9	1	
				GM	2,8	7	4,5	3,6,9	1
	38.50	4.60	J	MIN	2,4	1			3,5-9
				GM	2	4	1		3,5-9
			A	MIN	2	4,8	5		1,3,6,7,9
				GM	2		4,8	5	1,3,6,7,9
	14.9	1.87	J	MIN	2,4		1		3,5-9
				GM	2	4		1	3,5-9
			A	MIN	2,8	4,5	3	6,7,9	1
				GM	2	8	4,5	3,6	1,7,9
010	0.74	0.13	J	MIN	2,3,4		7,8		1,5,6,9
				GM	2	3,4		7,8	1,5,6,9
			A	MIN	2,7,8,9	3,4,5	1,6		
				GM	7,8	2	3,4,5,6,9	1	
	7.78	1.28	J	MIN	2,3,4			1,7,8	5,6,9
				GM	2	4	3	7	1,5,6,8,9
			A	MIN	2,7,8	3,4,5,9	1,6		
				GM	2,7,8		3,4,5,9	1,6	
011	24.0	2.27	J	MIN	2,4			1	3,5-9
				GM	2	4			1,3,5-9
			A	MIN	2	4,8	5	6	1,3,7,9
				GM	2		4,8	5	1,3,6,7,9
	123.0	10.87	J	MIN	1,2,4				3,5-9
				GM	2	1	4		3,5-9
			A	MIN	2		5,8	1,4	3,6,7,9
				GM	2			4,5,8	1,3,6,7,9

* 1 = Bluegill, 2 = Bluntnose, 3 = Carp, 4 = Channel Cat, 5 = Largemouth Bass, 6 = Smallmouth Bass, 7 = Drum, 8 = White Bass, 9 = White Crappie

† J and A denote Juvenile and Adult, respectively.

shown in figure 25 for net water supply of 10 percent of mean flow, 25-year drought, and b = 0.75, for the following three stations:

020	Kishwaukee River at Belvidere	C_o = \$1.399 million
021	S.B. Kishwaukee River near Fairdale	C_o = \$3.848 million
022	Kishwaukee River near Perryville	C_o = \$2.133 million

The C_o is much higher for station 021 because the low flows are not as well sustained as for stations 020 and 022. The information used in developing the curves in figure 25 is given in tables 16 through 21.

For the Kishwaukee River at Belvidere, the average fish preference for the riffles is negligible for the adults and rather small for the juveniles for the low flow range of 36.9 to 92 cfs. In the pools, the juvenile fish preference increases from 0.55 to 0.62 with MIN and from 0.65 to 0.68 with GM as the flow increases from 36.9 to 92 cfs (the 7-day 10-year low flow is 34.3 cfs). The preference for the adults increases from 0.20 to 0.43 with MIN and from 0.35 to 0.56 with GM. The cost-preference curve has practically the same slope for the low flow release range studied.

In the case of South Branch Kishwaukee River near Fairdale, the average fish preference for the riffles is negligible or very small for the juveniles and adults, for the low flow range of 10.1 to 28.6 cfs. In the pools, the juvenile fish preference is 0.53 with MIN and 0.63 with GM for the entire flow range considered. The preference for the adults increases from 0.14 to 0.20 with MIN and 0.30 to 0.34 with GM as flow increases from 10.1 to 28.6 cfs (the extra capital cost increases from \$1.50 to \$4.14 million). The 7-day 10-year low flow is 9.9 cfs.

For the Kishwaukee River, the average fish preference for the riffles is negligible for the adults and is 0.14 with MIN and 0.18 with GM for the juveniles, for the flow range of 69 to 156 cfs (the 7-day 10-year low

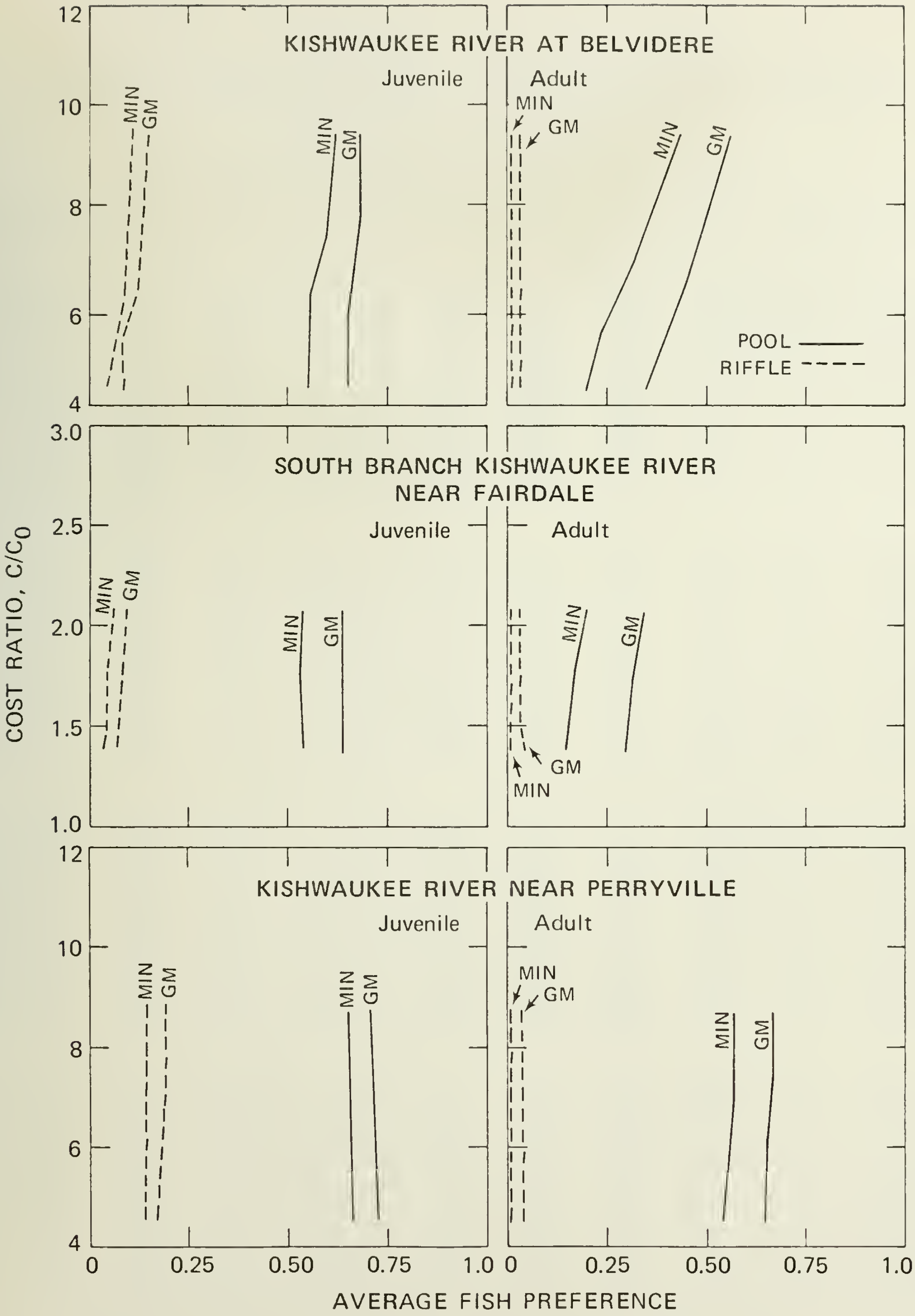


Figure 25. Cost ratio vs. average fish preference: Kishwaukee River Basin

Table 16. Fish Suitability (MIN Criterion) for the Range of Low Flow Releases

Station No. 20 ; USGS No. 05438500 ; Kishwaukee River at Belvidere
D.A. 538 Sq Mi ; Mean Flow 337 cfs ; Q(7,10) 34.3 cfs

Q		Suitability for Fish Number										
cfs	No.	1	2	3	4	5	6	7	8	9	avg	C/C_o
A. Juvenile (riffle condition)												
36.90	2	.00	.02	.00	.00	.16	.22	.00	.00	.00	.04	4.38
46.00	4	.00	.02	.00	.00	.21	.27	.00	.00	.00	.06	5.24
57.22	5	.00	.01	.00	.00	.25	.34	.00	.00	.14	.08	6.32
59.65	7	.00	.01	.00	.00	.27	.35	.00	.00	.17	.09	6.55
64.36	6	.00	.01	.00	.00	.27	.33	.00	.00	.23	.09	6.98
68.57	8	.00	.00	.00	.00	.26	.32	.00	.00	.29	.10	7.38
73.70	1	.00	.00	.00	.00	.25	.30	.00	.00	.35	.10	7.86
92.00	3	.00	.00	.00	.00	.22	.26	.00	.00	.55	.11	9.42
B. Adult (riffle condition)												
36.90	2	.00	.09	.00	.00	.00	.00	.00	.00	.00	.01	4.38
46.00	4	.00	.08	.00	.00	.00	.00	.00	.00	.00	.01	5.24
57.22	5	.00	.07	.00	.00	.00	.00	.00	.00	.00	.01	6.32
59.65	7	.00	.07	.00	.00	.00	.00	.00	.00	.00	.01	6.55
64.36	6	.00	.07	.00	.00	.00	.00	.00	.00	.00	.01	6.98
68.57	8	.00	.06	.00	.00	.00	.00	.00	.00	.00	.01	7.38
73.70	1	.00	.06	.00	.00	.00	.00	.00	.00	.00	.01	7.86
92.00	3	.01	.05	.00	.00	.00	.00	.00	.00	.00	.01	9.42
C. Juvenile (pool condition)												
36.90	2	.37	.00	.16	.08	.98	1.00	.66	.69	1.00	.55	4.38
46.00	4	.28	.00	.20	.08	.97	1.00	.70	.72	1.00	.55	5.24
57.22	5	.19	.00	.34	.08	.96	1.00	.75	.74	1.00	.56	6.32
59.65	7	.18	.00	.40	.08	.95	1.00	.76	.75	1.00	.57	6.55
64.36	6	.15	.00	.49	.08	.94	1.00	.77	.76	.99	.58	6.98
68.57	8	.13	.00	.59	.08	.94	.99	.79	.77	.99	.59	7.38
73.70	1	.12	.00	.68	.08	.93	.99	.80	.77	.99	.60	7.86
92.00	3	.07	.00	.89	.08	.90	.96	.85	.81	.98	.62	9.42
D. Adult (pool condition)												
36.90	2	.55	.00	.22	.15	.18	.45	.00	.00	.27	.20	4.38
46.00	4	.61	.00	.25	.16	.19	.48	.05	.00	.33	.23	5.24
57.22	5	.67	.00	.30	.16	.20	.51	.24	.00	.43	.28	6.32
59.65	7	.69	.00	.31	.17	.21	.52	.31	.00	.46	.30	6.55
64.36	6	.71	.00	.33	.17	.21	.54	.40	.00	.50	.32	6.98
68.57	8	.73	.00	.37	.17	.22	.55	.50	.00	.54	.34	7.38
73.70	1	.76	.00	.41	.17	.22	.56	.59	.00	.57	.36	7.86
92.00	3	.77	.00	.60	.19	.24	.61	.76	.05	.68	.43	9.42

Note: Q = Minimum flow release

C/C_o = Ratio of reservoir cost with Q to that with Q=0 (T=25 years, net water supply equals 10% of mean flow)

Table 17. Fish Suitability (GM Criterion) for the Range of Low Flow Releases

Station No. 20 ; USGS No. 05438500 ; Kishwaukee River at Belvidere
D.A. 538 Sq Mi ; Mean Flow 337 cfs : Q(7,10) 34.3 cfs

Q		Suitability for Fish Number										
cfs	No.	1	2	3	4	5	6	7	8	9	avg	C/C_o
A. Juvenile (riffle condition)												
36.90	2	.00	.15	.00	.00	.25	.32	.00	.00	.00	.08	4.38
46.00	4	.00	.12	.00	.00	.26	.33	.00	.00	.00	.08	5.24
57.22	5	.00	.09	.00	.00	.27	.35	.00	.00	.33	.12	6.32
59.65	7	.00	.08	.00	.00	.28	.35	.00	.00	.37	.12	6.55
64.36	6	.00	.05	.00	.00	.28	.35	.00	.00	.42	.12	6.98
68.57	8	.00	.03	.00	.00	.29	.36	.00	.00	.47	.13	7.38
73.70	1	.00	.02	.00	.00	.29	.36	.00	.00	.51	.13	7.86
92.00	3	.00	.00	.00	.03	.32	.37	.00	.00	.64	.15	9.42
B. Adult (riffle condition)												
36.90	2	.00	.30	.00	.00	.00	.00	.00	.00	.00	.03	4.38
46.00	4	.00	.28	.00	.00	.00	.00	.00	.00	.00	.03	5.24
57.22	5	.00	.27	.00	.00	.00	.00	.00	.00	.00	.03	6.32
59.65	7	.01	.26	.00	.00	.00	.00	.00	.00	.00	.03	6.55
64.36	6	.01	.26	.00	.00	.00	.00	.00	.00	.00	.03	6.98
68.57	8	.02	.25	.00	.00	.00	.00	.00	.00	.00	.03	7.38
73.70	1	.02	.24	.00	.00	.00	.00	.00	.00	.00	.03	7.86
92.00	3	.03	.20	.00	.00	.02	.04	.00	.00	.00	.03	9.42
C. Juvenile (pool condition)												
36.90	2	.60	.00	.41	.20	.99	1.00	.81	.83	1.00	.65	4.38
46.00	4	.53	.00	.45	.20	.98	1.00	.84	.85	1.00	.65	5.24
57.22	5	.44	.00	.58	.21	.98	1.00	.86	.86	1.00	.66	6.32
59.65	7	.42	.00	.63	.21	.98	1.00	.87	.86	1.00	.66	6.55
64.36	6	.39	.00	.70	.21	.97	1.00	.88	.87	1.00	.67	6.98
68.57	8	.36	.00	.76	.21	.97	1.00	.88	.87	1.00	.67	7.38
73.70	1	.34	.00	.82	.22	.96	.99	.89	.88	.99	.68	7.86
92.00	3	.27	.00	.93	.22	.95	.98	.92	.90	.99	.68	9.42
D. Adult (pool condition)												
36.90	2	.74	.04	.47	.39	.42	.58	.00	.00	.52	.35	4.38
46.00	4	.78	.02	.50	.39	.43	.60	.22	.00	.57	.39	5.24
57.22	5	.80	.00	.55	.40	.44	.62	.49	.00	.66	.44	6.32
59.65	7	.80	.00	.56	.41	.45	.63	.55	.00	.67	.45	6.55
64.36	6	.81	.00	.57	.41	.45	.64	.63	.00	.70	.47	6.98
68.57	8	.81	.00	.60	.41	.45	.64	.71	.00	.72	.48	7.38
73.70	1	.81	.00	.63	.41	.46	.65	.77	.00	.75	.50	7.86
92.00	3	.80	.00	.76	.42	.47	.68	.87	.22	.80	.56	9.42

Note: Q = Minimum flow release
C/C_o = Ratio of reservoir cost with Q to that with Q=0 (T=25 years, net water supply equals 10% of mean flow)

Table 18. Fish Suitability (MIN Criterion) for the Range of Low Flow Releases

Station No. 21 ; USGS No. 05439500 ; S. B. Kishwaukee River near Fairdale
D.A. 387 Sq Mi ; Mean Flow 253 cfs ; Q(7,10) 9.90 cfs

0		Suitability for Fish Number										
cfs	No.	1	2	3	4	5	6	7	8	9	avg	C/C_o
A. Juvenile (riffle condition)												
10.10	2	.00	.03	.00	.00	.10	.14	.00	.00	.00	.03	1.39
14.30	4	.00	.03	.00	.00	.12	.18	.00	.00	.00	.04	1.55
15.73	5	.00	.02	.00	.00	.13	.19	.00	.00	.00	.04	1.60
16.22	7	.00	.02	.00	.00	.13	.19	.00	.00	.00	.04	1.62
18.78	6	.00	.02	.00	.00	.16	.22	.00	.00	.00	.04	1.72
19.66	8	.00	.02	.00	.00	.16	.22	.00	.00	.00	.04	1.75
20.10	1	.00	.02	.00	.00	.16	.22	.00	.00	.00	.04	1.77
28.60	3	.00	.01	.00	.00	.22	.29	.00	.00	.02	.06	2.08
B. Adult (riffle condition)												
10.10	2	.00	.12	.00	.00	.00	.00	.00	.00	.00	.01	1.39
14.30	4	.00	.10	.00	.00	.00	.00	.00	.00	.00	.01	1.55
15.73	5	.00	.10	.00	.00	.00	.00	.00	.00	.00	.01	1.60
16.22	7	.00	.09	.00	.00	.00	.00	.00	.00	.00	.01	1.62
18.78	6	.00	.09	.00	.00	.00	.00	.00	.00	.00	.01	1.72
19.66	8	.00	.09	.00	.00	.00	.00	.00	.00	.00	.01	1.75
20.10	1	.00	.09	.00	.00	.00	.00	.00	.00	.00	.01	1.77
28.60	3	.00	.07	.00	.00	.00	.00	.00	.00	.00	.01	2.08
C. Juvenile (pool condition)												
10.10	2	.61	.00	.07	.08	.99	1.00	.47	.58	1.00	.53	1.39
14.30	4	.45	.00	.09	.08	.98	1.00	.53	.61	1.00	.53	1.55
15.73	5	.42	.00	.10	.08	.98	1.00	.54	.62	1.00	.53	1.60
16.22	7	.41	.00	.10	.08	.98	1.00	.54	.62	1.00	.53	1.62
18.78	6	.33	.00	.11	.08	.98	1.00	.58	.64	1.00	.52	1.72
19.66	8	.31	.00	.11	.08	.97	1.00	.58	.64	1.00	.52	1.75
20.10	1	.31	.00	.11	.08	.97	1.00	.58	.64	1.00	.52	1.77
28.60	3	.21	.00	.16	.08	.96	1.00	.65	.69	1.00	.53	2.08
D. Adult (pool condition)												
10.10	2	.38	.01	.15	.12	.13	.36	.00	.00	.12	.14	1.39
14.30	4	.41	.01	.16	.13	.15	.38	.00	.00	.16	.16	1.55
15.73	5	.43	.01	.17	.13	.15	.39	.00	.00	.17	.16	1.60
16.22	7	.43	.01	.17	.13	.15	.39	.00	.00	.17	.16	1.62
18.78	6	.45	.00	.18	.14	.16	.41	.00	.00	.19	.17	1.72
19.66	8	.46	.00	.19	.14	.16	.41	.00	.00	.19	.17	1.75
20.10	1	.46	.00	.19	.14	.16	.41	.00	.00	.19	.17	1.77
28.60	3	.54	.00	.21	.15	.17	.44	.00	.00	.26	.20	2.08

Note: Q = Minimum flow release
C/C_o = Ratio of reservoir cost with Q to that with Q=0 (T=25 years, net water supply equals 10% of mean flow)

Table 19. Fish Suitability (GM Criterion) for the Range of Low Flow Releases

Station No. 21 ; USGS No. 05439500 ; S. B. Kishwaukee River near Fairdale
D.A. 387 Sq Mi ; Mean Flow 253 cfs ; Q(7,10) 9.90 cfs

Q		Suitability for Fish Number										
cfs	No.	1	2	3	4	5	6	7	8	9	avg	C/C_o
A. Juvenile (riffle condition)												
10.10	2	.00	.15	.00	.00	.22	.28	.00	.00	.00	.07	1.39
14.30	4	.00	.15	.00	.00	.23	.30	.00	.00	.00	.08	1.55
15.73	5	.00	.15	.00	.00	.24	.30	.00	.00	.00	.08	1.60
16.22	7	.00	.15	.00	.00	.23	.30	.00	.00	.00	.08	1.62
18.78	6	.00	.14	.00	.00	.25	.31	.00	.00	.00	.08	1.72
19.66	8	.00	.14	.00	.00	.25	.31	.00	.00	.00	.08	1.75
20.10	1	.00	.14	.00	.00	.25	.31	.00	.00	.00	.08	1.77
28.60	3	.00	.10	.00	.00	.26	.33	.00	.00	.12	.09	2.08
B. Adult (riffle condition)												
10.10	2	.00	.35	.00	.00	.00	.00	.00	.00	.00	.04	1.39
14.30	4	.00	.31	.00	.00	.00	.00	.00	.00	.00	.03	1.55
15.73	5	.00	.31	.00	.00	.00	.00	.00	.00	.00	.03	1.60
16.22	7	.00	.31	.00	.00	.00	.00	.00	.00	.00	.03	1.62
18.78	6	.00	.30	.00	.00	.00	.00	.00	.00	.00	.03	1.72
19.66	8	.00	.30	.00	.00	.00	.00	.00	.00	.00	.03	1.75
20.10	1	.00	.30	.00	.00	.00	.00	.00	.00	.00	.03	1.77
28.60	3	.00	.27	.00	.00	.00	.00	.00	.00	.00	.03	2.08
C. Juvenile (pool condition)												
10.10	2	.78	.00	.27	.19	1.00	1.00	.68	.76	1.00	.63	1.39
14.30	4	.67	.00	.31	.19	.99	1.00	.73	.78	1.00	.63	1.55
15.73	5	.65	.00	.32	.19	.99	1.00	.74	.79	1.00	.63	1.60
16.22	7	.64	.00	.32	.19	.99	1.00	.74	.79	1.00	.63	1.62
18.78	6	.57	.00	.33	.20	.99	1.00	.76	.80	1.00	.63	1.72
19.66	8	.56	.00	.34	.20	.99	1.00	.76	.80	1.00	.63	1.75
20.10	1	.56	.00	.34	.20	.99	1.00	.76	.80	1.00	.63	1.77
28.60	3	.46	.00	.39	.20	.98	1.00	.80	.83	1.00	.63	2.08
D. Adult (pool condition)												
10.10	2	.61	.08	.38	.35	.37	.52	.00	.00	.35	.30	1.39
14.30	4	.64	.07	.40	.36	.38	.54	.00	.00	.39	.31	1.55
15.73	5	.65	.07	.41	.36	.39	.54	.00	.00	.41	.31	1.60
16.22	7	.65	.07	.41	.36	.39	.54	.00	.00	.41	.31	1.62
18.78	6	.67	.06	.43	.37	.40	.55	.00	.00	.43	.32	1.72
19.66	8	.68	.05	.43	.37	.40	.55	.00	.00	.44	.32	1.75
20.10	1	.68	.05	.43	.37	.40	.55	.00	.00	.44	.32	1.77
28.60	3	.72	.03	.46	.38	.41	.58	.00	.00	.51	.34	2.08

Note: Q = Minimum flow release
C/C_o = Ratio of reservoir cost with Q to that with Q=0 (T=25 years, net water supply equals 10% of mean flow)

Table 20. Fish Suitability (MIN Criterion) for the Range of Low Flow Releases

Station No. 22 ; USGS No. 05440000 ; Kishwaukee River near Perryville
D.A. 1099 Sq Mi ; Mean Flow 690 cfs ; Q(7,10) 62.3 cfs

Q		Suitability for Fish Number										
cfs	No.	1	2	3	4	5	6	7	8	9	avg	C/C_o
A. Juvenile (riffle condition)												
69.00	2	.00	.02	.00	.00	.38	.44	.00	.00	.46	.14	4.52
78.00	4	.00	.02	.00	.00	.36	.42	.00	.00	.50	.14	4.98
107.00	5	.00	.01	.00	.02	.29	.36	.00	.00	.61	.14	6.39
111.00	7	.00	.01	.00	.02	.28	.35	.00	.00	.62	.14	6.59
121.00	6	.00	.01	.00	.03	.27	.33	.00	.00	.65	.14	7.08
128.00	8	.00	.00	.00	.03	.26	.32	.00	.00	.68	.14	7.41
138.00	1	.00	.00	.00	.04	.25	.30	.00	.00	.69	.14	7.90
156.00	3	.00	.00	.00	.05	.24	.28	.00	.00	.71	.14	8.79
B. Adult (riffle condition)												
69.00	2	.01	.09	.00	.00	.00	.00	.00	.00	.00	.01	4.52
78.00	4	.01	.08	.00	.00	.00	.00	.00	.00	.00	.01	4.98
107.00	5	.01	.07	.00	.00	.00	.01	.00	.00	.00	.01	6.39
111.00	7	.01	.07	.00	.00	.00	.01	.00	.00	.00	.01	6.59
121.00	6	.01	.07	.00	.00	.01	.01	.00	.00	.00	.01	7.08
128.00	8	.01	.06	.00	.00	.01	.01	.00	.00	.00	.01	7.41
138.00	1	.02	.06	.00	.00	.01	.02	.00	.00	.00	.01	7.90
156.00	3	.02	.05	.00	.00	.01	.02	.00	.00	.00	.01	8.79
C. Juvenile (pool condition)												
69.00	2	.23	.00	.96	.08	.96	1.00	.92	.86	1.00	.67	4.52
78.00	4	.20	.00	.96	.08	.96	1.00	.92	.86	1.00	.66	4.98
107.00	5	.13	.00	.97	.08	.94	.99	.94	.88	.99	.66	6.39
111.00	7	.12	.00	.97	.08	.93	.99	.95	.88	.99	.66	6.59
121.00	6	.11	.00	.98	.08	.93	.99	.95	.89	.99	.66	7.08
128.00	8	.10	.00	.98	.08	.92	.98	.96	.89	.98	.65	7.41
138.00	1	.10	.00	.98	.08	.92	.97	.96	.89	.98	.65	7.90
156.00	3	.08	.00	.98	.08	.91	.97	.97	.90	.98	.65	8.79
D. Adult (pool condition)												
69.00	2	.91	.00	.92	.21	.27	.70	.89	.13	.80	.54	4.52
78.00	4	.92	.00	.94	.21	.27	.71	.90	.13	.81	.54	4.98
107.00	5	.89	.00	.97	.23	.29	.74	.94	.16	.84	.56	6.39
111.00	7	.88	.00	.97	.23	.29	.75	.94	.17	.85	.56	6.59
121.00	6	.86	.00	.97	.23	.29	.76	.95	.18	.86	.57	7.08
128.00	8	.85	.00	.98	.24	.29	.76	.96	.19	.87	.57	7.41
138.00	1	.83	.00	.98	.24	.30	.76	.96	.19	.87	.57	7.90
156.00	3	.79	.00	.97	.25	.30	.76	.97	.20	.89	.57	8.79

Note: Q = Minimum flow release
C/C_o = Ratio of reservoir cost with Q to that with Q=0 (T=25 years, net water supply equals 10% of mean flow)

Table 21. Fish Suitability (GM Criterion) for the Range of Low Flow Releases

Station No. 22 ; USGS No. 05440000 ; Kishwaukee River near Perryville
D.A. 1099 Sq Mi ; Mean Flow 690 cfs : Q(7,10) 62.3 cfs

Q		Suitability for Fish Number										
cfs	No.	1	2	3	4	5	6	7	8	9	avg	C/C_o
A. Juvenile (riffle condition)												
69.00	2	.00	.07	.00	.00	.39	.46	.00	.00	.62	.17	4.52
78.00	4	.00	.06	.00	.00	.39	.46	.00	.00	.64	.17	4.98
107.00	5	.00	.04	.00	.05	.40	.46	.00	.00	.70	.18	6.39
111.00	7	.00	.03	.00	.05	.41	.46	.00	.00	.70	.18	6.59
121.00	6	.00	.03	.00	.06	.41	.47	.00	.00	.71	.19	7.08
128.00	8	.00	.02	.00	.07	.42	.47	.00	.00	.72	.19	7.41
138.00	1	.00	.01	.00	.08	.42	.46	.00	.00	.73	.19	7.90
156.00	3	.00	.00	.00	.09	.43	.46	.00	.00	.73	.19	8.79
B. Adult (riffle condition)												
69.00	2	.03	.29	.00	.00	.00	.00	.00	.00	.00	.04	4.52
78.00	4	.03	.28	.00	.00	.00	.00	.00	.00	.00	.03	4.98
107.00	5	.03	.21	.00	.00	.04	.08	.00	.00	.00	.04	6.39
111.00	7	.03	.19	.00	.00	.04	.09	.00	.00	.00	.04	6.59
121.00	6	.04	.17	.00	.00	.05	.10	.00	.00	.00	.04	7.08
128.00	8	.04	.16	.00	.00	.05	.11	.00	.00	.00	.04	7.41
138.00	1	.04	.15	.00	.00	.05	.12	.00	.00	.00	.04	7.90
156.00	3	.04	.14	.00	.00	.06	.14	.00	.00	.00	.04	8.79
C. Juvenile (pool condition)												
69.00	2	.48	.00	.98	.22	.98	1.00	.96	.93	1.00	.73	4.52
78.00	4	.44	.00	.98	.23	.98	1.00	.96	.93	1.00	.72	4.98
107.00	5	.36	.00	.98	.23	.97	1.00	.97	.94	1.00	.72	6.39
111.00	7	.35	.00	.98	.23	.97	1.00	.97	.94	.99	.71	6.59
121.00	6	.34	.00	.98	.23	.96	.99	.97	.94	.99	.71	7.08
128.00	8	.32	.00	.98	.23	.96	.99	.98	.94	.99	.71	7.41
138.00	1	.31	.00	.98	.23	.96	.99	.98	.94	.99	.71	7.90
156.00	3	.29	.00	.98	.24	.95	.98	.98	.95	.99	.71	8.79
D. Adult (pool condition)												
69.00	2	.94	.00	.96	.46	.52	.72	.94	.35	.89	.64	4.52
78.00	4	.94	.00	.97	.46	.52	.73	.95	.37	.90	.65	4.98
107.00	5	.92	.00	.98	.47	.52	.75	.97	.40	.91	.66	6.39
111.00	7	.92	.00	.98	.47	.52	.75	.97	.41	.91	.66	6.59
121.00	6	.91	.00	.98	.48	.53	.76	.97	.42	.91	.66	7.08
128.00	8	.91	.00	.98	.48	.53	.76	.98	.43	.92	.67	7.41
138.00	1	.90	.00	.98	.48	.53	.77	.98	.44	.92	.67	7.90
156.00	3	.88	.00	.98	.49	.53	.77	.99	.45	.92	.67	8.79

Note: Q = Minimum flow release
C/C_o = Ratio of reservoir cost with Q to that with Q=0 (T=25 years, net water supply equals 10% of mean flow)

TABLE 22. Costs and Fish Preferences: Kishwaukee River Basin (Pool Condition)

	Q	ΔC			Fish number* with preference				
No.	cfs	10^6 $	†	Crit	<0.1	0.10-0.24	0.25-0.49	0.50-0.74	0.75-1.00
020	36.9	4.731	J	MIN	2,4	3	1	7,8	5,6,9
				GM	2	4	3	1	5,6,7,8,9
			A	MIN	2,7,8	3,4,5	6,9	1	
				GM	2,7,8		3,4,5	1,6,9	
	92.0	11.775	J	MIN	1,2,4				3,5-9
				GM	2	4	1		3,5-9
			A	MIN	2,8	4,5		3,6,9	1,7
				GM	2	8	4,5	6	1,3,7,9
021	10.1	1.505	J	MIN	2,3,4		7	1,8	5,6,9
				GM	2	4	3	7	1,5,6,8,9
			A	MIN	2,7,8	3,4,5,9	1,6		
				GM	2,7,8		3,4,5,9	1,6	
	28.6	4.144	J	MIN	2,4	1,3		7,8	5,6,9
				GM	2	4	1,3		5,6,7,8,9
			A	MIN	2,7,8	3,4,5	6,9	1	
				GM	2,7,8		3,4,5	1,6,9	
022	69.0	7.507	J	MIN	2,4	1			3,5-9
				GM	2	4	1		3,5-9
			A	MIN	2	4,8	5	6	1,3,7,9
				GM	2		4,8	5,6	1,3,7,9
	156.0	16.623	J	MIN	1,2,4				3,5-9
				GM	2	4	1		3,5-9
			A	MIN	2	8	4,5		1,3,6,7,9
				GM	2		4,8	5	1,3,6,7,9

* 1 = Bluegill, 2 = Bluntnose, 3 = Carp, 4 = Channel Cat, 5 = Largemouth Bass, 6 = Smallmouth Bass, 7 = Drum, 8 = White Bass, 9 = White Crappie

† J and A denote Ju~~n~~evnile and Adult, respectively.

flow is 62.3 cfs). In the pools, the juvenile fish preference is about 0.66 with MIN and 0.72 with GM over the low flow range studied. Similarly, the preference for the adult fish is about 0.55 with MIN and 0.66 with GM. The fish preferences need to be calculated at flows less than 69 cfs to determine if a lesser flow release may be appropriate.

A summary of the fish preferences at the two ends of the low flow range is given in table 22. The decision on a suitable low flow release will be governed by the relative importance of the different target fish, their preferences, and extra capital costs, ΔC.

III. *Bay Creek Basin.* Cost ratio vs average fish preference curves for juvenile and adult species, applicable to riffle and pool conditions, are shown in figure 26 for net water supply of 10 percent of mean flow, 25-year design drought, and b = 0.75 for the following three stations:

039 Hadley Creek at Kinderhook C_o = \$3.865 million
040 Bay Creek at Pittsfield C_o = \$2.764 million
041 Bay Creek at Nebo C_o = \$5.918 million

The information used in developing the curves in figure 26 is given in tables 23 through 28. The 7-day 10-year low flows at all the above stations are zero.

For Hadley Creek at Kinderhook (drainage area 72.7 sq mi), the average fish preference for the riffles is negligible for both juveniles and adults for the low flow range of 0.19 to 4.50 cfs. In the pools, the juvenile fish preference is about 0.45 with MIN and 0.48 with GM for the low flow range studied. The preference for the adults is much lower, about 0.03 with MIN and 0.13 with GM. The preferences are rather independent of the flow for the range 0.19 to 4.50 cfs.

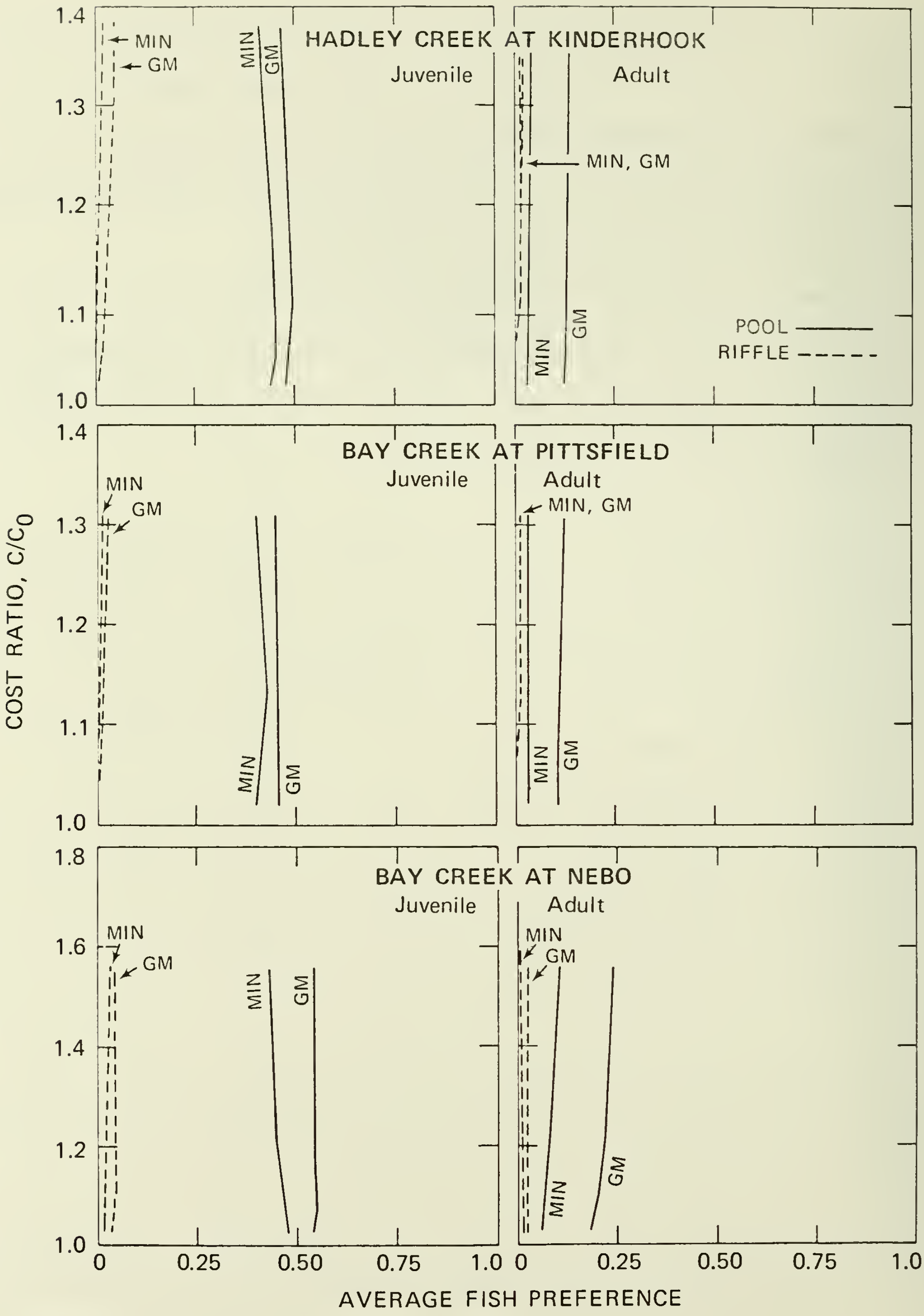


Figure 26. Cost ratio vs. average fish preference: Bay Creek Basin

Table 23. Fish Suitability (MIN Criterion) for the Range of Low Flow Releases

Station No. 39 ; USGS No. 05510500 ; Hadley Creek at Kinderhook
D.A. 72.7 Sq Mi ; Mean Flow 53.5 cfs ; Q(7,10) 0.00 cfs

Q		Suitability for Fish Number										
cfs	No.	1	2	3	4	5	6	7	8	9	avg	C/C_o
A. Juvenile (riffle condition)												
.19	5	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	1.02
.53	6	.00	.00	.00	.00	.00	.01	.00	.00	.00	.00	1.05
.58	7	.00	.00	.00	.00	.00	.02	.00	.00	.00	.00	1.05
.76	2	.00	.00	.00	.00	.00	.02	.00	.00	.00	.00	1.05
1.16	8	.00	.00	.00	.00	.01	.03	.00	.00	.00	.00	1.09
1.52	1	.00	.00	.00	.00	.02	.05	.00	.00	.00	.01	1.11
2.25	4	.00	.00	.00	.00	.03	.06	.00	.00	.00	.01	1.17
4.50	3	.00	.02	.00	.00	.06	.09	.00	.00	.00	.02	1.38
B. Adult (riffle condition)												
.19	5	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	1.02
.53	6	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	1.05
.58	7	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	1.05
.76	2	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	1.05
1.16	8	.00	.08	.00	.00	.00	.00	.00	.00	.00	.01	1.09
1.52	1	.00	.14	.00	.00	.00	.00	.00	.00	.00	.02	1.11
2.25	4	.00	.12	.00	.00	.00	.00	.00	.00	.00	.01	1.17
4.50	3	.00	.09	.00	.00	.00	.00	.00	.00	.00	.01	1.38
C. Juvenile (pool condition)												
.19	5	.90	.00	.00	.07	1.00	1.00	.00	.05	.94	.44	1.02
.53	6	.93	.00	.00	.07	1.00	1.00	.00	.07	.96	.45	1.05
.58	7	.94	.00	.00	.07	1.00	1.00	.00	.08	.97	.45	1.05
.76	2	.95	.00	.00	.07	1.00	1.00	.00	.09	.97	.45	1.05
1.16	8	.94	.00	.00	.07	.99	1.00	.00	.10	.98	.45	1.09
1.52	1	.87	.00	.00	.07	.99	1.00	.00	.12	.99	.45	1.11
2.25	4	.74	.00	.00	.07	.99	1.00	.00	.14	1.00	.44	1.17
4.50	3	.44	.00	.00	.08	.98	1.00	.00	.18	1.00	.41	1.38
D. Adult (pool condition)												
.19	5	.07	.12	.01	.00	.03	.07	.00	.00	.00	.03	1.02
.53	6	.08	.10	.01	.00	.04	.08	.00	.00	.00	.03	1.05
.58	7	.08	.10	.01	.00	.04	.09	.00	.00	.00	.04	1.05
.76	2	.08	.09	.01	.00	.04	.09	.00	.00	.00	.03	1.05
1.16	8	.09	.09	.02	.00	.04	.10	.00	.00	.00	.04	1.09
1.52	1	.10	.08	.02	.00	.04	.11	.00	.00	.00	.04	1.11
2.25	4	.11	.07	.02	.00	.05	.12	.00	.00	.00	.04	1.17
4.50	3	.12	.05	.03	.00	.06	.14	.00	.00	.00	.04	1.38

Note: Q = Minimum flow release
C/C_o = Ratio of reservoir cost with Q to that with Q=0 (T=25 years, net water supply equals 10% of mean flow)

Table 24. Fish Suitability (GM Criterion) for the Range of Low Flow Releases

Station No. 39 ; USGS No. 05510500 ; Hadley Creek at Kinderhook
D.A. 72.7 Sq Mi ; Mean Flow 53.5 cfs ; Q(7,10) 0.00 cfs

Q		Suitability for Fish Number										
cfs	No.	1	2	3	4	5	6	7	8	9	avg	C/C_o
A. Juvenile (riffle condition)												
.19	5	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	1.02
.53	6	.00	.00	.00	.00	.00	.10	.00	.00	.00	.01	1.05
.58	7	.00	.00	.00	.00	.00	.11	.00	.00	.00	.01	1.05
.76	2	.00	.00	.00	.00	.00	.13	.00	.00	.00	.01	1.05
1.16	8	.00	.00	.00	.00	.06	.15	.00	.00	.00	.02	1.09
1.52	1	.00	.00	.00	.00	.10	.17	.00	.00	.00	.03	1.11
2.25	4	.00	.00	.00	.00	.12	.18	.00	.00	.00	.03	1.17
4.50	3	.00	.06	.00	.00	.15	.20	.00	.00	.00	.05	1.38
B. Adult (riffle condition)												
.19	5	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	1.02
.53	6	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	1.05
.58	7	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	1.05
.76	2	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	1.05
1.16	8	.00	.11	.00	.00	.00	.00	.00	.00	.00	.01	1.09
1.52	1	.00	.15	.00	.00	.00	.00	.00	.00	.00	.02	1.11
2.25	4	.00	.17	.00	.00	.00	.00	.00	.00	.00	.02	1.17
4.50	3	.00	.21	.00	.00	.00	.00	.00	.00	.00	.02	1.38
C. Juvenile (pool condition)												
.19	5	.95	.00	.00	.11	1.00	1.00	.00	.23	.97	.47	1.02
.53	6	.96	.00	.00	.11	1.00	1.00	.00	.27	.98	.48	1.05
.58	7	.96	.00	.00	.12	1.00	1.00	.00	.28	.98	.48	1.05
.76	2	.96	.00	.00	.12	1.00	1.00	.00	.30	.99	.49	1.05
1.16	8	.96	.00	.00	.12	1.00	1.00	.00	.32	.99	.49	1.09
1.52	1	.93	.00	.00	.13	1.00	1.00	.00	.34	.99	.49	1.11
2.25	4	.86	.00	.00	.13	1.00	1.00	.00	.37	1.00	.48	1.17
4.50	3	.66	.00	.00	.14	.99	1.00	.00	.42	1.00	.46	1.38
D. Adult (pool condition)												
.19	5	.26	.34	.09	.00	.18	.23	.00	.00	.00	.12	1.02
.53	6	.28	.32	.11	.00	.19	.25	.00	.00	.00	.13	1.05
.58	7	.28	.31	.11	.00	.19	.25	.00	.00	.00	.13	1.05
.76	2	.29	.30	.12	.00	.20	.26	.00	.00	.00	.13	1.05
1.16	8	.30	.29	.13	.00	.20	.27	.00	.00	.00	.13	1.09
1.52	1	.31	.27	.14	.00	.21	.28	.00	.00	.00	.13	1.11
2.25	4	.32	.25	.15	.00	.22	.30	.00	.00	.00	.14	1.17
4.50	3	.35	.20	.17	.00	.24	.33	.00	.00	.00	.14	1.38

Note: Q = Minimum flow release

C/C_o = Ratio of reservoir cost with Q to that with Q=0 (T=25 years, net water supply equals 10% of mean flow)

Table 25. Fish Suitability (MIN Criterion) for the Range of Low Flow Releases

Station No. 40 ; USGS No. 05512500 ; Bay Creek at Pittsfield
D.A. 39.4 Sq Mi ; Mean Flow 26.7 cfs ; Q(7,10) 0.00 cfs

Q		Suitability for Fish Number										
cfs	No.	1	2	3	4	5	6	7	8	9	avg	C/C_o
A. Juvenile (riffle condition)												
.15	5	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	1.02
.20	7	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	1.02
.23	6	.00	.00	.00	.00	.00	.01	.00	.00	.00	.00	1.03
.27	2	.00	.00	.00	.00	.00	.01	.00	.00	.00	.00	1.03
.30	8	.00	.00	.00	.00	.00	.01	.00	.00	.00	.00	1.04
.53	1	.00	.00	.00	.00	.00	.02	.00	.00	.00	.00	1.07
.96	4	.00	.00	.00	.00	.01	.03	.00	.00	.00	.00	1.13
1.91	3	.00	.00	.00	.00	.03	.06	.00	.00	.00	.01	1.31
B. Adult (riffle condition)												
.15	5	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	1.02
.20	7	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	1.02
.23	6	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	1.03
.27	2	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	1.03
.30	8	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	1.04
.53	1	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	1.07
.96	4	.00	.08	.00	.00	.00	.00	.00	.00	.00	.01	1.13
1.91	3	.00	.08	.00	.00	.00	.00	.00	.00	.00	.01	1.31
C. Juvenile (pool condition)												
.15	5	.63	.06	.00	.07	.95	1.00	.00	.00	.85	.40	1.02
.20	7	.65	.06	.00	.07	.95	1.00	.00	.00	.86	.40	1.02
.23	6	.67	.06	.00	.07	.96	1.00	.00	.00	.86	.40	1.03
.27	2	.67	.06	.00	.07	.96	1.00	.00	.00	.86	.40	1.03
.30	8	.69	.05	.00	.07	.97	1.00	.00	.00	.87	.41	1.04
.53	1	.75	.04	.00	.07	.98	1.00	.00	.00	.88	.41	1.07
.96	4	.81	.03	.00	.07	.99	1.00	.00	.01	.90	.42	1.13
1.91	3	.49	.01	.00	.08	.99	1.00	.00	.04	.93	.39	1.31
D. Adult (pool condition)												
.15	5	.04	.19	.00	.00	.02	.05	.00	.00	.00	.03	1.02
.20	7	.04	.18	.00	.00	.02	.05	.00	.00	.00	.03	1.02
.23	6	.04	.17	.00	.00	.02	.05	.00	.00	.00	.03	1.03
.27	2	.04	.17	.00	.00	.02	.05	.00	.00	.00	.03	1.03
.30	8	.04	.17	.00	.00	.02	.05	.00	.00	.00	.03	1.04
.53	1	.05	.15	.00	.00	.03	.05	.00	.00	.00	.03	1.07
.96	4	.05	.14	.00	.00	.03	.06	.00	.00	.00	.03	1.13
1.91	3	.06	.12	.01	.00	.03	.07	.00	.00	.00	.03	1.31

Note: Q = Minimum flow release
C/C_o = Ratio of reservoir cost with Q to that with Q=0 (T=25 years, net water supply equals 10% of mean flow)

Table 26. Fish Suitability (GM Criterion) for the Range of Low Flow Releases

Station No. 40 ; USGS No. 05512500 ; Bay Creek at Pittsfield
D.A. 39.4 Sq Mi ; Mean Flow 26.7 cfs ; Q(7,10) 0.00 cfs

Q		Suitability for Fish Number										
cfs	No.	1	2	3	4	5	6	7	8	9	avg	C/C_o
A. Juvenile (riffle condition)												
.15	5	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	1.02
.20	7	.00	.00	.00	.00	.00	.06	.00	.00	.00	.01	1.02
.23	6	.00	.00	.00	.00	.00	.08	.00	.00	.00	.01	1.03
.27	2	.00	.00	.00	.00	.00	.08	.00	.00	.00	.01	1.03
.30	8	.00	.00	.00	.00	.00	.10	.00	.00	.00	.01	1.04
.53	1	.00	.00	.00	.00	.00	.12	.00	.00	.00	.01	1.07
.96	4	.00	.00	.00	.00	.06	.14	.00	.00	.00	.02	1.13
1.91	3	.00	.00	.00	.00	.09	.15	.00	.00	.00	.03	1.31
B. Adult (riffle condition)												
.15	5	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	1.02
.20	7	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	1.02
.23	6	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	1.03
.27	2	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	1.03
.30	8	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	1.04
.53	1	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	1.07
.96	4	.00	.09	.00	.00	.00	.00	.00	.00	.00	.01	1.13
1.91	3	.00	.13	.00	.00	.00	.00	.00	.00	.00	.01	1.31
C. Juvenile (pool condition)												
.15	5	.80	.25	.00	.09	.97	1.00	.00	.00	.92	.45	1.02
.20	7	.81	.24	.00	.09	.98	1.00	.00	.00	.93	.45	1.02
.23	6	.82	.23	.00	.09	.98	1.00	.00	.00	.93	.45	1.03
.27	2	.81	.23	.00	.09	.98	1.00	.00	.00	.93	.45	1.03
.30	8	.83	.23	.00	.09	.98	1.00	.00	.00	.93	.45	1.04
.53	1	.85	.20	.00	.10	.99	1.00	.00	.00	.94	.45	1.07
.96	4	.82	.17	.00	.10	.99	1.00	.00	.09	.95	.46	1.13
1.91	3	.66	.09	.00	.11	.99	1.00	.00	.19	.96	.44	1.31
D. Adult (pool condition)												
.15	5	.20	.43	.00	.00	.15	.18	.00	.00	.00	.11	1.02
.20	7	.20	.42	.00	.00	.15	.19	.00	.00	.00	.11	1.02
.23	6	.21	.41	.00	.00	.15	.19	.00	.00	.00	.11	1.03
.27	2	.21	.41	.00	.00	.15	.19	.00	.00	.00	.11	1.03
.30	8	.21	.40	.00	.00	.15	.19	.00	.00	.00	.11	1.04
.53	1	.22	.38	.00	.00	.16	.20	.00	.00	.00	.11	1.07
.96	4	.23	.36	.04	.00	.17	.21	.00	.00	.00	.11	1.13
1.91	3	.25	.32	.08	.00	.18	.22	.00	.00	.00	.12	1.31

Note: Q = Minimum flow release
C/C_o = Ratio of reservoir cost with Q to that with Q=0 (T=25 years, net water supply equals 10% of mean flow)

Table 27. Fish Suitability (MIN Criterion) for the Range of Low Flow Releases

Station No. 41 ; USGS No. 05513000 ; Bay Creek at Nebo
D.A. 161 Sq Mi ; Mean Flow 96.7 cfs ; Q(7,10) 0.00 cfs

Q		Suitability for Fish Number										
cfs	No.	1	2	3	4	5	6	7	8	9	avg	C/C_o
A. Juvenile (riffle condition)												
.69	5	.00	.00	.00	.00	.02	.05	.00	.00	.00	.01	1.03
1.13	7	.00	.00	.00	.00	.03	.06	.00	.00	.00	.01	1.05
1.50	6	.00	.02	.00	.00	.04	.07	.00	.00	.00	.01	1.07
1.81	2	.00	.02	.00	.00	.04	.08	.00	.00	.00	.02	1.08
2.38	8	.00	.02	.00	.00	.05	.08	.00	.00	.00	.02	1.10
3.62	1	.00	.01	.00	.00	.06	.10	.00	.00	.00	.02	1.15
5.25	4	.00	.00	.00	.00	.08	.12	.00	.00	.00	.02	1.22
10.50	3	.00	.00	.00	.00	.11	.16	.00	.00	.00	.03	1.56
B. Adult (riffle condition)												
.69	5	.00	.13	.00	.00	.00	.00	.00	.00	.00	.01	1.03
1.13	7	.00	.11	.00	.00	.00	.00	.00	.00	.00	.01	1.05
1.50	6	.00	.10	.00	.00	.00	.00	.00	.00	.00	.01	1.07
1.81	2	.00	.09	.00	.00	.00	.00	.00	.00	.00	.01	1.08
2.38	8	.00	.08	.00	.00	.00	.00	.00	.00	.00	.01	1.10
3.62	1	.00	.07	.00	.00	.00	.00	.00	.00	.00	.01	1.15
5.25	4	.00	.06	.00	.00	.00	.00	.00	.00	.00	.01	1.22
10.50	3	.00	.03	.00	.00	.00	.00	.00	.00	.00	.00	1.56
C. Juvenile (pool condition)												
.69	5	.92	.00	.00	.07	.99	1.00	.06	.24	1.00	.48	1.03
1.13	7	.81	.00	.00	.07	.99	1.00	.08	.27	1.00	.47	1.05
1.50	6	.73	.00	.01	.07	.99	1.00	.10	.28	1.00	.46	1.07
1.81	2	.66	.00	.01	.08	.99	1.00	.11	.29	1.00	.46	1.08
2.38	8	.57	.00	.01	.08	.99	1.00	.13	.31	1.00	.45	1.10
3.62	1	.44	.00	.01	.08	.98	1.00	.15	.33	1.00	.44	1.15
5.25	4	.30	.00	.02	.08	.97	1.00	.19	.36	1.00	.44	1.22
10.50	3	.15	.00	.03	.08	.94	1.00	.26	.42	.99	.43	1.56
D. Adult (pool condition)												
.69	5	.16	.04	.05	.04	.07	.18	.00	.00	.00	.06	1.03
1.13	7	.17	.04	.05	.05	.08	.19	.00	.00	.00	.06	1.05
1.50	6	.17	.03	.05	.05	.08	.19	.00	.00	.00	.06	1.07
1.81	2	.18	.03	.06	.06	.08	.20	.00	.00	.00	.07	1.08
2.38	8	.18	.03	.06	.06	.08	.20	.00	.00	.00	.07	1.10
3.62	1	.20	.03	.07	.07	.09	.22	.00	.00	.01	.08	1.15
5.25	4	.21	.02	.08	.08	.09	.23	.00	.00	.02	.08	1.22
10.50	3	.25	.02	.09	.10	.10	.27	.00	.00	.05	.10	1.56

Note: Q = Minimum flow release
C/C_o = Ratio of reservoir cost with Q to that with Q=0 (T=25 years, net water supply equals 10% of mean flow)

Table 28. Fish Suitability (GM Criterion) for the Range of Low Flow Releases

Station No. 41 ; USGS No. 05513000 ; Bay Creek at Nebo
D.A. 161 Sq Mi ; Mean Flow 96.7 cfs ; Q(7,10) 0.00 cfs

Q		Suitability for Fish Number										
cfs	No.	1	2	3	4	5	6	7	8	9	avg	C/C_o
A. Juvenile (riffle condition)												
.69	5	.00	.00	.00	.00	.10	.16	.00	.00	.00	.03	1.03
1.13	7	.00	.00	.00	.00	.12	.18	.00	.00	.00	.03	1.05
1.50	6	.00	.03	.00	.00	.12	.18	.00	.00	.00	.04	1.07
1.81	2	.00	.04	.00	.00	.13	.18	.00	.00	.00	.04	1.08
2.38	8	.00	.05	.00	.00	.13	.19	.00	.00	.00	.04	1.10
3.62	1	.00	.04	.00	.00	.13	.19	.00	.00	.00	.04	1.15
5.25	4	.00	.00	.00	.00	.14	.19	.00	.00	.00	.04	1.22
10.50	3	.00	.00	.00	.00	.14	.18	.00	.00	.00	.04	1.56
B. Adult (riffle condition)												
.69	5	.00	.14	.00	.00	.00	.00	.00	.00	.00	.02	1.03
1.13	7	.00	.16	.00	.00	.00	.00	.00	.00	.00	.02	1.05
1.50	6	.00	.17	.00	.00	.00	.00	.00	.00	.00	.02	1.07
1.81	2	.00	.18	.00	.00	.00	.00	.00	.00	.00	.02	1.08
2.38	8	.00	.18	.00	.00	.00	.00	.00	.00	.00	.02	1.10
3.62	1	.00	.20	.00	.00	.00	.00	.00	.00	.00	.02	1.15
5.25	4	.00	.22	.00	.00	.00	.00	.00	.00	.00	.02	1.22
10.50	3	.00	.18	.00	.00	.00	.00	.00	.00	.00	.02	1.56
C. Juvenile (pool condition)												
.69	5	.96	.00	.02	.15	1.00	1.00	.24	.49	1.00	.54	1.03
1.13	7	.90	.00	.07	.15	1.00	1.00	.29	.52	1.00	.55	1.05
1.50	6	.86	.00	.08	.15	1.00	1.00	.31	.53	1.00	.55	1.07
1.81	2	.81	.00	.09	.16	1.00	1.00	.33	.54	1.00	.55	1.08
2.38	8	.75	.00	.10	.16	1.00	1.00	.35	.55	1.00	.55	1.10
3.62	1	.66	.00	.12	.16	.99	1.00	.39	.58	1.00	.54	1.15
5.25	4	.55	.00	.14	.17	.99	1.00	.43	.60	1.00	.54	1.22
10.50	3	.39	.00	.18	.18	.97	1.00	.50	.65	1.00	.54	1.56
D. Adult (pool condition)												
.69	5	.40	.19	.21	.20	.27	.36	.00	.00	.00	.18	1.03
1.13	7	.41	.18	.23	.22	.28	.37	.00	.00	.00	.19	1.05
1.50	6	.42	.18	.23	.23	.28	.38	.00	.00	.00	.19	1.07
1.81	2	.42	.17	.24	.24	.28	.38	.00	.00	.00	.19	1.08
2.38	8	.43	.17	.25	.25	.29	.39	.00	.00	.04	.20	1.10
3.62	1	.44	.15	.26	.26	.29	.40	.00	.00	.11	.21	1.15
5.25	4	.46	.12	.27	.28	.30	.42	.00	.00	.15	.22	1.22
10.50	3	.47	.08	.30	.31	.31	.45	.00	.00	.21	.24	1.56

Note: Q = Minimum flow release
C/C_o = Ratio of reservoir cost with Q to that with Q=0 (T=25 years, net water supply equals 10% of mean flow)

TABLE 29. Costs and Fish Preferences: Bay Creek Basin (Pool Condition)

No.	Q cfs	ΔC 10^6 $	†	Crit	Fish number* with preference <0.1	 0.10-0.24	 0.25-0.49	 0.50-0.74	 0.75-1.00
039	0.19	0.064	J	MIN	2,3,4,7,8				1,5,6,9
				GM	2,3,7	4,8			1,5,6,9
			A	MIN	1,3-9	2			
				GM	3,4,7,8,9		1,2,5,6		
	4.50	1.478	J	MIN	2,3,4,7	8	1		5,6,9
				GM	2,3,7	4	8	1	5,6,9
			A	MIN	2-5,7-9	1,6			
				GM	4,7,8,9	2,3,5	1,6		
040	0.15	0.066	J	MIN	2,3,4,7,8			1	5,6,9
				GM	3,4,7,8		2		1,5,6,9
			A	MIN	1,3-9	2			
				GM	3,4,7,8,9	2,5,6	2		
	1.91	0.870	J	MIN	2,3,4,7,8		1		5,6,9
				GM	2,3,7	4,8		1	5,6,9
			A	MIN	1,3-9	2			
				GM	3,4,7,8,9	5,6	1,2		
041	0.69	0.187	J	MIN	2,3,4,7	8			1,5,6,9
				GM	2,3	4,7	8		1,5,6,9
			A	MIN	2-5, 7-9	1,6			
				GM	7,8,9	2,3,4	1,5,6		
	10.50	3.291	J	MIN	2,3,4	1	7,8		5,6,9
				GM	2	3,4	1	7,8	5,6,9
			A	MIN	2,3,7,8,9	4,5	1,6		
				GM	2,7,8	9	1,3,4,5,6		

* 1 = Bluegill, 2 = Bluntnose, 3 = Carp, 4 = Channel Cat, 5 = Largemouth Bass, 6 = Smallmouth Bass, 7 = Drum, 8 = White Bass, 9 = White Crappie

† J and A denote Juvenile and Adult, respectively.

In the case of Bay Creek at Pittsfield (drainage area 39.4 sq mi), the average fish preference for the riffles is negligible for both juveniles and adults for the low flow range of 0.15 to 1.91 cfs. In the pools, the juvenile fish preference is about 0.40 with MIN and 0.45 with GM for the low flow range studied. The preference for the adults is much lower, about 0.03 with MIN and 0.11 with GM. The preferences are rather independent of the flow for the range of 0.15 to 1.91 cfs.

For Bay Creek at Nebo (drainage area 161 sq mi), the average fish preference for the riffles is negligible for both juveniles and adults for the low flow range of 0.69 to 10.50 cfs. In the pools, the juvenile fish preference is about 0.46 with MIN and 0.55 with GM for the low flow range studied. The preference for the adults is lower, varying from 0.06 to 0.10 with MIN and from 0.18 to 0.24 with GM.

A summary of the fish preferences at the two ends of the low flow range is given in table 29. It is evident that unless much higher flow releases are considered, it may be satisfactory to keep minimum low flow release for maintenance of the pools if the water quality is not adversely affected at low flows.

IV. *Vermilion River Basin.* Cost ratio vs average fish preference curves for juvenile and adult species, applicable to riffle and pool conditions, are given in figure 27 for net water supply of 10 percent of mean flow, 25-year design drought, and $b = 0.75$ for the following three stations:

079	N.F. Vermilion River near Charlotte	$C_o = \$3.989$ million
080	Vermilion River at Pontiac	$C_o = \$6.710$ million
081	Vermilion River at Lowell	$C_o = \$11.321$ million

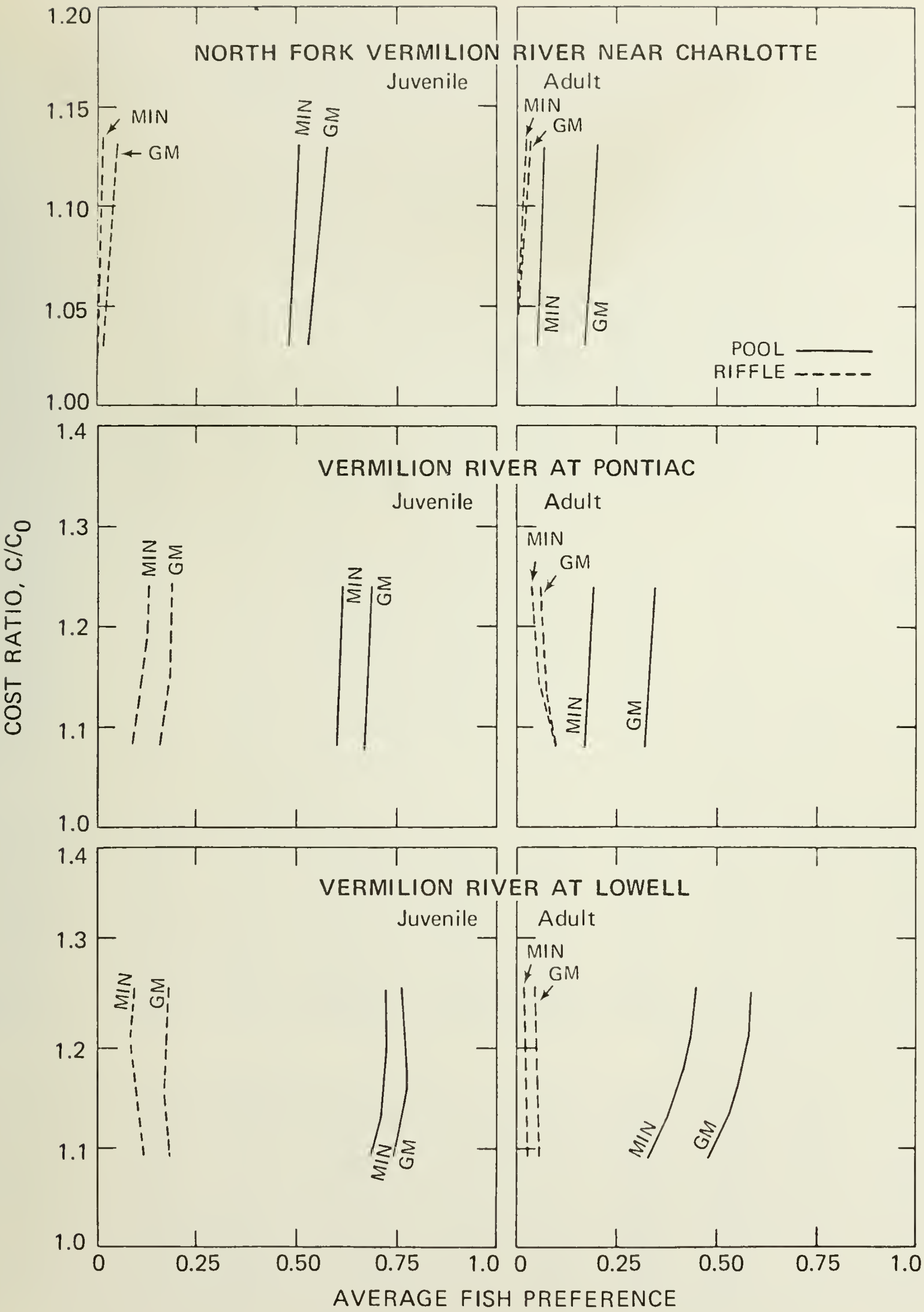


Figure 27. Cost ratio vs. average fish preference: Vermilion River Basin

The information used in developing the curves in figure 27 is given in tables 30 through 35. The 7-day 10-year low flows at the above stations are 0.00, 0.20, and 7.30 cfs. The 7-day 10-year low flow at Pontiac is 2.0 cfs, but 1.8 cfs is withdrawn by the town upstream of the gaging station.

For the North Fork Vermilion River near Charlotte (drainage area 186 sq mi), the average fish preference for the riffles is negligible for both juveniles and adults for the low flow range of 0.49 to 2.16 cfs. In the pools, the juvenile fish preference is about 0.49 with MIN and 0.55 with GM for the low flow range studied. The preference for the adults is much lower, about 0.06 with MIN and 0.18 with GM. The preferences do not vary appreciably with increases in low flow in the range of 0.49 to 2.16 cfs.

In the case of the Vermilion River at Pontiac (drainage area 579 sq mi), the average fish preference for the riffles increases from 0.09 to 0.13 with MIN and from 0.16 to 0.19 with GM for the juveniles, and decreases from 0.10 to 0.04 with MIN and 0.10 to 0.06 with GM for the adults, as the flow increases from 3.13 to 9.97 cfs. In the pools, the juvenile fish preference is about 0.60 with MIN and 0.68 with GM, and the adult fish preference is about 0.18 with MIN and 0.33 with GM for the low flow range studied. The preferences for the pools are practically independent of the low flow release within the study range.

For the Vermilion River at Lowell (drainage area 1278 sq mi), the average fish preference for the riffles is about 0.10 with MIN and 0.17 with GM for the juveniles, and about 0.03 and 0.05 for the adults for the low flow range of 8.95 to 26.20 cfs. In the pools, the juvenile fish preference is about 0.71 with MIN and 0.76 with GM, and the adult fish preference increases from 0.33 to 0.46 with MIN and from 0.48 to 0.59 with an increase in

Table 30. Fish Suitability (MIN Criterion) for the Range of Low Flow Releases

Station No. 79 ; USGS No. 05554000 ; N. F. Vermilion River near Charlotte
D.A. 186 Sq Mi ; Mean Flow 124 cfs ; Q(7,10) 0.00 cfs

Q		Suitability for Fish Number										
cfs	No.	1	2	3	4	5	6	7	8	9	avg	C/C_o
A. Juvenile (riffle condition)												
.49	5	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	1.03
.55	2	.00	.00	.00	.00	.00	.01	.00	.00	.00	.00	1.03
.73	7	.00	.00	.00	.00	.00	.02	.00	.00	.00	.00	1.05
.83	6	.00	.00	.00	.00	.00	.02	.00	.00	.00	.00	1.05
1.08	4	.00	.00	.00	.00	.00	.03	.00	.00	.00	.00	1.07
1.09	1	.00	.00	.00	.00	.00	.03	.00	.00	.00	.00	1.07
1.31	8	.00	.00	.00	.00	.01	.04	.00	.00	.00	.01	1.08
2.16	3	.00	.00	.00	.00	.03	.06	.00	.00	.00	.01	1.13
B. Adult (riffle condition)												
.49	5	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	1.03
.55	2	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	1.03
.73	7	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	1.05
.83	6	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	1.05
1.08	4	.00	.05	.00	.00	.00	.00	.00	.00	.00	.01	1.07
1.09	1	.00	.05	.00	.00	.00	.00	.00	.00	.00	.01	1.07
1.31	8	.00	.10	.00	.00	.00	.00	.00	.00	.00	.01	1.08
2.16	3	.00	.25	.00	.00	.00	.00	.00	.00	.00	.03	1.13
C. Juvenile (pool condition)												
.49	5	1.00	.00	.00	.07	1.00	1.00	.01	.21	1.00	.48	1.03
.55	2	1.00	.00	.00	.07	1.00	1.00	.02	.22	1.00	.48	1.03
.73	7	1.00	.00	.00	.07	1.00	1.00	.04	.23	1.00	.48	1.05
.83	6	1.00	.00	.00	.07	1.00	1.00	.04	.23	1.00	.48	1.05
1.08	4	1.00	.00	.00	.07	1.00	1.00	.06	.25	1.00	.49	1.07
1.09	1	1.00	.00	.00	.07	1.00	1.00	.06	.25	1.00	.49	1.07
1.31	8	1.00	.00	.00	.07	1.00	1.00	.08	.26	1.00	.49	1.08
2.16	3	1.00	.00	.01	.07	1.00	1.00	.12	.30	1.00	.50	1.13
D. Adult (pool condition)												
.49	5	.14	.04	.04	.02	.07	.16	.00	.00	.00	.05	1.03
.55	2	.14	.04	.04	.02	.07	.16	.00	.00	.00	.05	1.03
.73	7	.15	.04	.04	.03	.07	.17	.00	.00	.00	.06	1.05
.83	6	.15	.04	.04	.03	.07	.17	.00	.00	.00	.06	1.05
1.08	4	.16	.04	.05	.04	.07	.18	.00	.00	.00	.06	1.07
1.09	1	.16	.04	.05	.04	.07	.18	.00	.00	.00	.06	1.07
1.31	8	.17	.04	.05	.05	.07	.18	.00	.00	.00	.06	1.08
2.16	3	.18	.03	.06	.06	.08	.20	.00	.00	.00	.07	1.13

Note: Q = Minimum flow release
C/C_o = Ratio of reservoir cost with Q to that with Q=0 (T=25 years, net water supply equals 10% of mean flow)

Table 31. Fish Suitability (GM Criterion) for the Range of Low Flow Releases

Station No. 79 ; USGS No. 05554000 ; N. F. Vermilion River near Charlotte
D.A. 186 Sq Mi ; Mean Flow 124 cfs ; Q(7,10) 0.00 cfs

Q		Suitability for Fish Number										
cfs	No.	1	2	3	4	5	6	7	8	9	avg	C/C_o
A. Juvenile (riffle condition)												
.49	5	.00	.00	.00	.00	.00	.06	.00	.00	.00	.01	1.03
.55	2	.00	.00	.00	.00	.00	.09	.00	.00	.00	.01	1.03
.73	7	.00	.00	.00	.00	.00	.12	.00	.00	.00	.01	1.05
.83	6	.00	.00	.00	.00	.00	.14	.00	.00	.00	.02	1.05
1.08	4	.00	.00	.00	.00	.06	.17	.00	.00	.00	.03	1.07
1.09	1	.00	.00	.00	.00	.06	.17	.00	.00	.00	.03	1.07
1.31	8	.00	.00	.00	.00	.10	.19	.00	.00	.00	.03	1.08
2.16	3	.00	.00	.00	.00	.17	.25	.00	.00	.00	.05	1.13
B. Adult (riffle condition)												
.49	5	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	1.03
.55	2	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	1.03
.73	7	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	1.05
.83	6	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	1.05
1.08	4	.00	.16	.00	.00	.00	.00	.00	.00	.00	.02	1.07
1.09	1	.00	.16	.00	.00	.00	.00	.00	.00	.00	.02	1.07
1.31	8	.00	.22	.00	.00	.00	.00	.00	.00	.00	.02	1.08
2.16	3	.00	.33	.00	.00	.00	.00	.00	.00	.00	.04	1.13
C. Juvenile (pool condition)												
.49	5	1.00	.00	.00	.14	1.00	1.00	.12	.46	1.00	.52	1.03
.55	2	1.00	.00	.00	.14	1.00	1.00	.15	.47	1.00	.53	1.03
.73	7	1.00	.00	.00	.14	1.00	1.00	.19	.48	1.00	.53	1.05
.83	6	1.00	.00	.00	.14	1.00	1.00	.21	.48	1.00	.54	1.05
1.08	4	1.00	.00	.03	.15	1.00	1.00	.25	.50	1.00	.55	1.07
1.09	1	1.00	.00	.03	.15	1.00	1.00	.25	.50	1.00	.55	1.07
1.31	8	1.00	.00	.06	.15	1.00	1.00	.28	.51	1.00	.56	1.08
2.16	3	1.00	.00	.10	.15	1.00	1.00	.34	.55	1.00	.57	1.13
D. Adult (pool condition)												
.49	5	.38	.21	.19	.13	.26	.34	.00	.00	.00	.17	1.03
.55	2	.38	.21	.19	.14	.26	.34	.00	.00	.00	.17	1.03
.73	7	.39	.20	.20	.17	.26	.35	.00	.00	.00	.17	1.05
.83	6	.39	.20	.21	.18	.26	.35	.00	.00	.00	.18	1.05
1.08	4	.40	.19	.22	.21	.27	.36	.00	.00	.00	.18	1.07
1.09	1	.40	.19	.22	.21	.27	.36	.00	.00	.00	.18	1.07
1.31	8	.41	.19	.22	.22	.27	.37	.00	.00	.00	.19	1.08
2.16	3	.43	.18	.24	.24	.29	.38	.00	.00	.00	.20	1.13

Note: Q = Minimum flow release
C/C_o = Ratio of reservoir cost with Q to that with Q=0 (T=25 years, net water supply equals 10% of mean flow)

Table 32. Fish Suitability (MIN Criterion) for the Range of Low Flow Releases

Station No. 80 ; USGS No. 05554500 ; Vermilion River at Pontiac
D.A. 579 Sq Mi ; Mean Flow 378 cfs ; Q(7,10) 0.20 cfs

Q		Suitability for Fish Number										
cfs	No.	1	2	3	4	5	6	7	8	9	avg	C/C_o
A. Juvenile (riffle condition)												
3.13	2	.00	.57	.00	.00	.09	.13	.00	.00	.00	.09	1.08
4.31	5	.00	.67	.00	.00	.10	.15	.00	.00	.00	.10	1.11
4.99	4	.01	.70	.00	.00	.10	.15	.00	.00	.00	.11	1.13
5.77	7	.01	.77	.00	.00	.11	.16	.00	.00	.00	.12	1.14
6.26	1	.01	.77	.00	.00	.11	.16	.00	.00	.00	.12	1.16
6.70	6	.01	.80	.00	.00	.11	.17	.00	.00	.00	.12	1.17
8.22	8	.02	.85	.00	.00	.12	.18	.00	.00	.00	.13	1.20
9.97	3	.02	.80	.00	.00	.13	.19	.00	.00	.00	.13	1.24
B. Adult (riffle condition)												
3.13	2	.00	.87	.00	.00	.00	.00	.00	.00	.00	.10	1.08
4.31	5	.00	.80	.00	.00	.00	.00	.00	.00	.00	.09	1.11
4.99	4	.00	.70	.00	.00	.00	.00	.00	.00	.00	.08	1.13
5.77	7	.00	.55	.00	.00	.00	.00	.00	.00	.00	.06	1.14
6.26	1	.00	.50	.00	.00	.00	.00	.00	.00	.00	.06	1.16
6.70	6	.00	.44	.00	.00	.00	.00	.00	.00	.00	.05	1.17
8.22	8	.00	.36	.00	.00	.00	.00	.00	.00	.00	.04	1.20
9.97	3	.00	.32	.00	.00	.00	.00	.00	.00	.00	.04	1.24
C. Juvenile (pool condition)												
3.13	2	1.00	.00	.11	.07	1.00	1.00	.56	.63	1.00	.60	1.08
4.31	5	1.00	.00	.11	.07	1.00	1.00	.59	.64	1.00	.60	1.11
4.99	4	1.00	.00	.12	.07	1.00	1.00	.59	.65	1.00	.60	1.13
5.77	7	.99	.00	.13	.07	1.00	1.00	.61	.66	1.00	.61	1.14
6.26	1	.99	.00	.13	.07	1.00	1.00	.61	.66	1.00	.61	1.16
6.70	6	.99	.00	.13	.07	1.00	1.00	.61	.66	1.00	.61	1.17
8.22	8	.98	.00	.14	.07	1.00	1.00	.63	.67	1.00	.61	1.20
9.97	3	.97	.00	.15	.07	1.00	1.00	.64	.68	1.00	.61	1.24
D. Adult (pool condition)												
3.13	2	.44	.00	.18	.14	.15	.40	.00	.00	.18	.17	1.08
4.31	5	.46	.00	.19	.14	.16	.41	.00	.00	.19	.17	1.11
4.99	4	.47	.00	.19	.14	.16	.41	.00	.00	.20	.17	1.13
5.77	7	.49	.00	.20	.14	.16	.42	.00	.00	.21	.18	1.14
6.26	1	.49	.00	.20	.14	.16	.42	.00	.00	.21	.18	1.16
6.70	6	.50	.00	.20	.14	.16	.42	.00	.00	.22	.18	1.17
8.22	8	.51	.00	.21	.14	.17	.43	.00	.00	.23	.19	1.20
9.97	3	.53	.00	.21	.15	.17	.44	.00	.00	.25	.19	1.24

Note: Q = Minimum flow release
C/C_o = Ratio of reservoir cost with Q to that with Q=0 (T=25 years, net water supply equals 10% of mean flow)

Table 33. Fish Suitability (GM Criterion) for the Range of Low Flow Releases

Station No. 80 ; USGS No. 05554500 ; Vermilion River at Pontiac
D.A. 579 Sq Mi ; Mean Flow 378 cfs ; Q(7,10) 0.20 cfs

Q		Suitability for Fish Number										
cfs	No.	1	2	3	4	5	6	7	8	9	avg	C/C_o
A. Juvenile (riffle condition)												
3.13	2	.00	.74	.00	.00	.30	.36	.00	.00	.00	.16	1.08
4.13	5	.03	.79	.00	.00	.31	.38	.00	.00	.00	.17	1.11
4.99	4	.04	.81	.00	.00	.32	.39	.00	.00	.00	.17	1.13
5.77	7	.05	.84	.00	.00	.33	.40	.00	.00	.00	.18	1.14
6.26	1	.05	.83	.00	.00	.33	.40	.00	.00	.00	.18	1.16
6.70	6	.06	.85	.00	.00	.33	.41	.00	.00	.00	.18	1.17
8.22	8	.06	.86	.00	.00	.34	.43	.00	.00	.00	.19	1.20
9.97	3	.05	.86	.00	.00	.35	.44	.00	.00	.00	.19	1.24
B. Adult (riffle condition)												
3.13	2	.00	.91	.00	.00	.00	.00	.00	.00	.00	.10	1.08
4.13	5	.00	.89	.00	.00	.00	.00	.00	.00	.00	.10	1.11
4.99	4	.00	.84	.00	.00	.00	.00	.00	.00	.00	.09	1.13
5.77	7	.00	.74	.00	.00	.00	.00	.00	.00	.00	.08	1.14
6.26	1	.00	.70	.00	.00	.00	.00	.00	.00	.00	.08	1.16
6.70	6	.00	.67	.00	.00	.00	.00	.00	.00	.00	.07	1.17
8.22	8	.00	.60	.00	.00	.00	.00	.00	.00	.00	.07	1.20
9.97	3	.00	.56	.00	.00	.00	.00	.00	.00	.00	.06	1.24
C. Juvenile (pool condition)												
3.13	2	1.00	.00	.32	.19	1.00	1.00	.75	.79	1.00	.67	1.08
4.13	5	1.00	.00	.34	.19	1.00	1.00	.76	.80	1.00	.68	1.11
4.99	4	1.00	.00	.34	.19	1.00	1.00	.77	.81	1.00	.68	1.13
5.77	7	1.00	.00	.35	.19	1.00	1.00	.78	.81	1.00	.68	1.14
6.26	1	1.00	.00	.35	.19	1.00	1.00	.78	.81	1.00	.68	1.16
6.70	6	.99	.00	.36	.19	1.00	1.00	.78	.81	1.00	.68	1.17
8.22	8	.99	.00	.38	.19	1.00	1.00	.79	.82	1.00	.69	1.20
9.97	3	.99	.00	.39	.19	1.00	1.00	.80	.83	1.00	.69	1.24
D. Adult (pool condition)												
3.13	2	.66	.07	.42	.37	.39	.54	.00	.00	.42	.32	1.08
4.13	5	.68	.07	.43	.37	.40	.55	.00	.00	.44	.33	1.11
4.99	4	.69	.06	.44	.37	.40	.55	.00	.00	.44	.33	1.13
5.77	7	.70	.06	.44	.38	.40	.56	.00	.00	.46	.33	1.14
6.26	1	.70	.06	.44	.38	.40	.56	.00	.00	.46	.33	1.16
6.70	6	.70	.06	.45	.38	.41	.56	.00	.00	.47	.34	1.17
8.22	8	.72	.06	.45	.38	.41	.56	.00	.00	.48	.34	1.20
9.97	3	.73	.05	.46	.38	.41	.57	.00	.00	.50	.34	1.24

Note: Q = Minimum flow release
C/C_o = Ratio of reservoir cost with Q to that with Q=0 (T=25 years, net water supply equals 10% of mean flow)

Table 34. Fish Suitability (MIN Criterion) for the Range of Low Flow Releases

Station No. 81 ; USGS No. 05555500 ; Vermilion River at Lowell
D.A. 1278 Sq Mi ; Mean Flow 734 cfs ; Q(7,10) 7.30 cfs

Q		Suitability for Fish Number										
cfs	No.	1	2	3	4	5	6	7	8	9	avg	C/C_o
A. Juvenile (riffle condition)												
8.95	2	.02	.74	.00	.00	.13	.19	.00	.00	.00	.12	1.09
13.10	4	.04	.51	.00	.00	.16	.22	.00	.00	.00	.10	1.13
13.92	5	.04	.47	.00	.00	.17	.23	.00	.00	.00	.10	1.14
15.37	7	.04	.42	.00	.00	.18	.24	.00	.00	.00	.10	1.16
17.90	1	.03	.33	.00	.00	.20	.26	.00	.00	.00	.09	1.18
17.93	6	.03	.33	.00	.00	.20	.26	.00	.00	.00	.09	1.18
20.90	8	.02	.20	.00	.00	.22	.29	.00	.00	.02	.08	1.21
26.20	3	.00	.16	.00	.00	.24	.32	.00	.00	.10	.09	1.26
B. Adult (riffle condition)												
8.95	2	.00	.29	.00	.00	.00	.00	.00	.00	.00	.03	1.09
13.10	4	.00	.27	.00	.00	.00	.00	.00	.00	.00	.03	1.13
13.92	5	.00	.26	.00	.00	.00	.00	.00	.00	.00	.03	1.14
15.37	7	.00	.25	.00	.00	.00	.00	.00	.00	.00	.03	1.16
17.90	1	.00	.24	.00	.00	.00	.00	.00	.00	.00	.03	1.18
17.93	6	.00	.24	.00	.00	.00	.00	.00	.00	.00	.03	1.18
20.90	8	.00	.22	.00	.00	.00	.00	.00	.00	.00	.02	1.21
26.20	3	.00	.21	.00	.00	.00	.00	.00	.00	.00	.02	1.26
C. Juvenile (pool condition)												
8.95	2	.97	.00	.56	.07	1.00	1.00	.78	.76	1.00	.68	1.09
13.10	4	.95	.00	.75	.07	.99	1.00	.81	.78	1.00	.71	1.13
13.92	5	.94	.00	.78	.07	.99	1.00	.81	.78	1.00	.71	1.14
15.37	7	.92	.00	.84	.07	.99	1.00	.82	.79	1.00	.71	1.16
17.90	1	.88	.00	.86	.07	.99	1.00	.84	.80	1.00	.72	1.18
17.93	6	.88	.00	.86	.07	.99	1.00	.84	.80	1.00	.72	1.18
20.90	8	.83	.00	.89	.07	.99	1.00	.85	.81	1.00	.72	1.21
26.20	3	.76	.00	.92	.07	.99	1.00	.87	.82	1.00	.71	1.26
D. Adult (pool condition)												
8.95	2	.73	.00	.35	.17	.21	.55	.47	.00	.52	.33	1.09
13.10	4	.78	.00	.44	.18	.22	.57	.63	.01	.60	.38	1.13
13.92	5	.78	.00	.45	.18	.23	.58	.64	.01	.61	.39	1.14
15.37	7	.80	.00	.48	.18	.23	.59	.67	.02	.64	.40	1.16
17.90	1	.81	.00	.54	.18	.23	.60	.72	.03	.66	.42	1.18
17.93	6	.81	.00	.54	.18	.23	.60	.72	.03	.66	.42	1.18
20.90	8	.83	.00	.61	.19	.24	.61	.76	.05	.68	.44	1.21
26.20	3	.85	.00	.69	.19	.25	.63	.79	.06	.71	.46	1.26

Note: Q = Minimum flow release
C/C_o = Ratio of reservoir cost with Q to that with Q=0 (T=25 years, net water supply equals 10% of mean flow)

Table 35. Fish Suitability (GM Criterion) for the Range of Low Flow Releases

Station No. 81 ; USGS No. 05555500 ; Vermilion River at Lowell
D.A. 1278 Sq Mi ; Mean Flow 734 cfs ; Q(7,10) 7.30 cfs

Q		Suitability for Fish Number										
cfs	No.	1	2	3	4	5	6	7	8	9	avg	C/C_o
A. Juvenile (riffle condition)												
8.95	2	.05	.81	.00	.00	.34	.43	.00	.00	.00	.18	1.09
13.10	4	.05	.72	.00	.00	.38	.46	.00	.00	.00	.18	1.13
13.92	5	.04	.68	.00	.00	.38	.46	.00	.00	.00	.17	1.14
15.37	7	.05	.65	.00	.00	.39	.47	.00	.00	.00	.17	1.16
17.90	1	.04	.58	.00	.00	.41	.49	.00	.00	.00	.17	1.18
17.93	6	.04	.58	.00	.00	.41	.49	.00	.00	.00	.17	1.18
20.90	8	.04	.44	.00	.00	.42	.50	.00	.00	.14	.17	1.21
26.20	3	.02	.38	.00	.00	.43	.52	.00	.00	.30	.18	1.26
B. Adult (riffle condition)												
8.95	2	.00	.54	.00	.00	.00	.00	.00	.00	.00	.06	1.09
13.10	4	.00	.52	.00	.00	.00	.00	.00	.00	.00	.06	1.13
13.92	5	.00	.51	.00	.00	.00	.00	.00	.00	.00	.06	1.14
15.37	7	.00	.50	.00	.00	.00	.00	.00	.00	.00	.06	1.16
17.90	1	.00	.49	.00	.00	.00	.00	.00	.00	.00	.05	1.18
17.93	6	.00	.49	.00	.00	.00	.00	.00	.00	.00	.05	1.18
20.90	8	.00	.47	.00	.00	.00	.00	.00	.00	.00	.05	1.21
26.20	3	.00	.46	.00	.00	.00	.00	.00	.00	.00	.05	1.26
C. Juvenile (pool condition)												
8.95	2	.99	.00	.75	.20	1.00	1.00	.88	.87	1.00	.74	1.09
13.10	4	.97	.00	.86	.20	1.00	1.00	.90	.88	1.00	.76	1.13
13.92	5	.97	.00	.88	.21	1.00	1.00	.90	.89	1.00	.76	1.14
15.37	7	.96	.00	.92	.21	1.00	1.00	.91	.89	1.00	.77	1.16
17.90	1	.94	.00	.93	.21	1.00	1.00	.92	.89	1.00	.77	1.18
17.93	6	.94	.00	.93	.21	1.00	1.00	.92	.89	1.00	.77	1.18
20.90	8	.91	.00	.94	.21	1.00	1.00	.92	.90	1.00	.76	1.21
26.20	3	.87	.00	.96	.21	1.00	1.00	.93	.91	1.00	.76	1.26
D. Adult (pool condition)												
8.95	2	.85	.00	.59	.41	.46	.63	.69	.00	.72	.48	1.09
13.10	4	.88	.00	.66	.42	.47	.65	.79	.09	.78	.53	1.13
13.92	5	.89	.00	.67	.42	.48	.65	.80	.11	.78	.53	1.14
15.37	7	.89	.00	.69	.42	.48	.66	.82	.15	.80	.55	1.16
17.90	1	.90	.00	.74	.43	.48	.67	.85	.19	.81	.56	1.18
17.93	6	.90	.00	.74	.43	.48	.67	.85	.19	.81	.56	1.18
20.90	8	.91	.00	.78	.43	.49	.67	.87	.22	.83	.58	1.21
26.20	3	.92	.00	.83	.44	.50	.68	.89	.25	.84	.59	1.26

Note: Q = Minimum flow release
C/C_o = Ratio of reservoir cost with Q to that with Q=0 (T=25 years, net water supply equals 10% of mean flow)

TABLE 36. Costs and Fish Preferences: Vermilion River Basin (Pool Condition)

	Q	ΔC			Fish number* with preference				
No.	cfs	$10^6\$$	†	Crit	<0.1	0.10-0.24	0.25-0.49	0.50-0.74	0.75-1.00
079	0.49	0.124	J	MIN	2,3,4,7	8			1,5,6,9
				GM	2,3	4,7	8		1,5,6,9
			A	MIN	2-5,7-9	1,6			
				GM	7,8,9	2,3,4	1,5,6		
	2.16	0.530	J	MIN	2,3,4	7	8		1,5,6,9
				GM	2	3,4	7	8	1,5,6,9
			A	MIN	2-5,7-9	1,6			
				GM	7,8,9	2,3,4	1,5,6		
080	3.13	0.532	J	MIN	2,4	3		7,8	1,5,6,9
				GM	2	4	3		1,5-9
			A	MIN	2,7,8	3,4,5,9	1,6		
				GM	2,7,8		3,4,5,9	1,6	
	9.97	1.628	J	MIN	2,4	3		7,8	1,5,6,9
				GM	2	4	3		1,5-9
			A	MIN	2,7,8	3,4,5	6,9	1	
				GM	2,7,8		3,4,5,9	1,6	
081	8.95	1.036	J	MIN	2,4			3	1,5-9
				GM	2	4			1,3,5-9
			A	MIN	2,8	4,5	3,7	1,6,9	
				GM	2,8		4,5	3,6,7,9	1
	26.20	2.970	J	MIN	2,4				1,3,5-9
				GM	2	4			1,3,5-9
			A	MIN	2,8	4	5	3,6,9	1,7
				GM	2		4,8	5,6	1,3,7,9

* 1 = Bluegill, 2 = Bluntnose, 3 = Carp, 4 = Channel Cat, 5 = Largemouth Bass, 6 = Smallmouth Bass, 7 = Drum, 8 = White Bass, 9 = White Crappie

† J and A denote Juvenile and Adult, respectively.

flow from 8.95 to 26.20 cfs. The cost-preference curve steepens as the ratio $^{C}/_{C_o}$ increases.

A summary of the fish preferences at the two ends of the low flow range is given in Table 36. It is evident that unless much higher flow releases are considered, it may be satisfactory to keep minimum low flow releases for maintenance of the pools if the water quality is not affected adversely at low flows. Generally, the fish preferences increase with drainage area, largely because of higher pool depths.

V. *S.F. Sangamon River Basin.* Cost ratio vs average fish preference curves for juvenile and adult species, applicable to riffle and pool conditions, are drawn in figure 28 for a net water supply of 10 percent of mean flow, 25-year design drought, and b = 0.75, for the following three stations:

096	Flat Branch near Taylorville	C_o = \$ 5.877 million
097	S.F. Sangamon River at Kincaid	C_o = \$ 7.765 million
098	S.F. Sangamon River near Rochester	C_o = \$11.164 million

The information used in developing the curves in figure 28 is given in tables 37 through 42. The 7-day 10-year low flows at the above stations are 0.00, 0.79 and 0.84 cfs.

For the Flat Branch near Taylorville (drainage area 276 sq mi), the average fish preference for the riffles is about 0.06 with MIN and 0.13 with GM for the juveniles and about 0.03 and 0.02 for the adults, for the low flow range of 1.02 to 8.17 cfs. In the pools, the juvenile fish preference is about 0.55 with MIN and 0.64 with GM for the low flow range studied. The preference for the adults is much lower, from 0.11 to 0.16 with MIN and from 0.26 to 0.31 with GM as the flow increases from 1.02 to 8.17 cfs. The preferences do not increase appreciably with increase in flow.

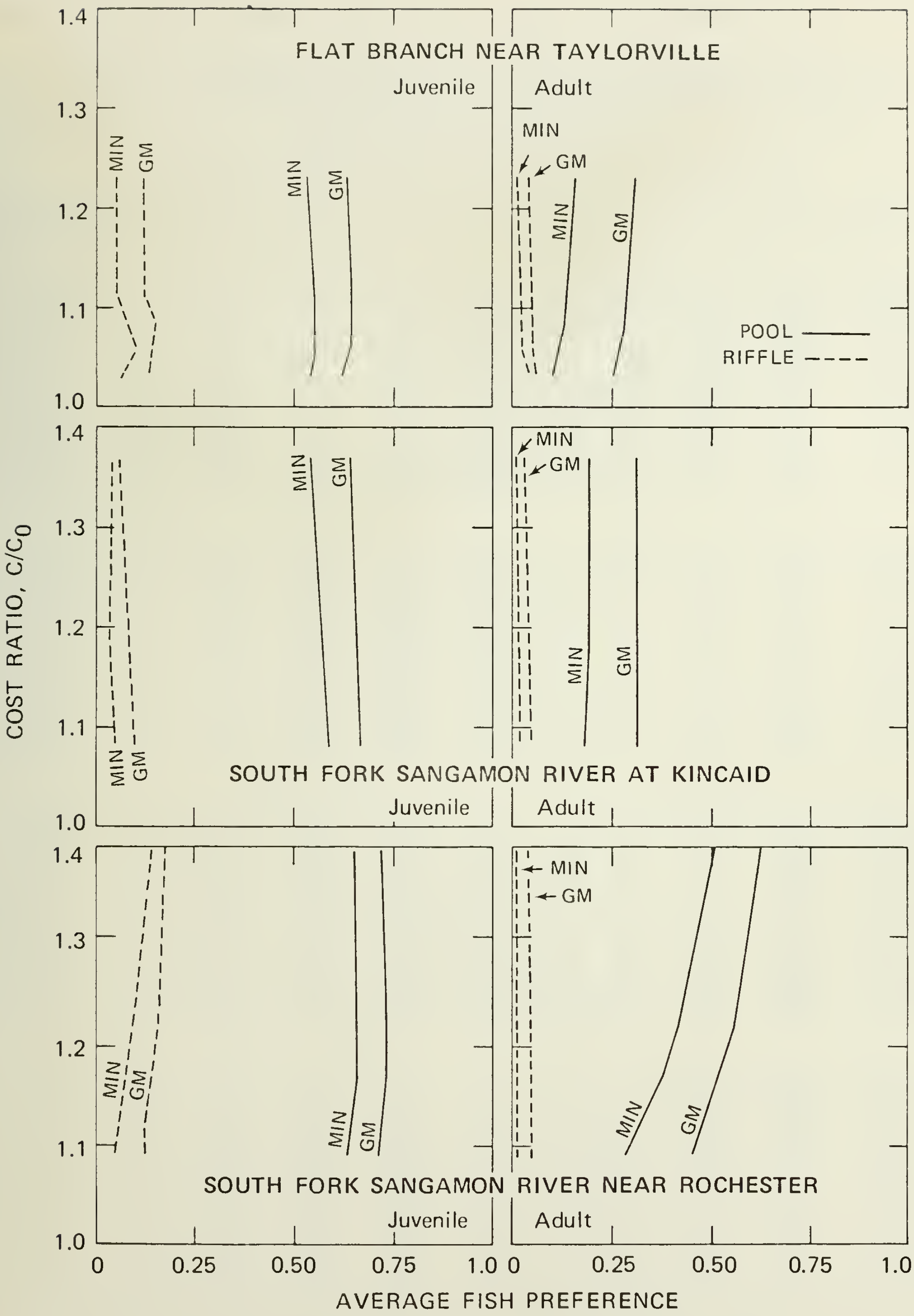


Figure 28. Cost ratio vs. average fish preference: S.F. Sangamon Basin

Table 37. Fish Suitability (MIN Criterion) for the Range of Low Flow Releases

Station No. 96 ; USGS No. 05574500 ; Flat Branch near Taylorville
D.A. 276 Sq Mi ; Mean Flow 203 cfs ; Q(7,10) 0.00 cfs

Q		Suitability for Fish Number										
cfs	No.	1	2	3	4	5	6	7	8	9	avg	C/C_o
A. Juvenile (riffle condition)												
1.02	5	.00	.36	.00	.00	.07	.11	.00	.00	.00	.06	1.03
1.76	2	.00	.60	.00	.00	.09	.14	.00	.00	.00	.09	1.05
2.04	7	.00	.60	.00	.00	.10	.15	.00	.00	.00	.09	1.06
2.90	6	.01	.33	.00	.00	.11	.17	.00	.00	.00	.07	1.09
3.52	1	.02	.20	.00	.00	.12	.18	.00	.00	.00	.08	1.10
3.90	8	.01	.17	.00	.00	.13	.19	.00	.00	.00	.05	1.11
4.08	4	.00	.16	.00	.00	.13	.19	.00	.00	.00	.05	1.12
8.17	3	.00	.05	.00	.00	.19	.25	.00	.00	.00	.05	1.23
B. Adult (riffle condition)												
1.02	5	.00	.36	.00	.00	.00	.00	.00	.00	.00	.04	1.03
1.76	2	.00	.29	.00	.00	.00	.00	.00	.00	.00	.03	1.05
2.04	7	.00	.28	.00	.00	.00	.00	.00	.00	.00	.03	1.06
2.90	6	.00	.24	.00	.00	.00	.00	.00	.00	.00	.03	1.09
3.52	1	.00	.22	.00	.00	.00	.00	.00	.00	.00	.02	1.10
3.90	8	.00	.21	.00	.00	.00	.00	.00	.00	.00	.02	1.11
4.08	4	.00	.21	.00	.00	.00	.00	.00	.00	.00	.02	1.12
8.17	3	.00	.15	.00	.00	.00	.00	.00	.00	.00	.02	1.23
C. Juvenile (pool condition)												
1.02	5	.99	.00	.04	.07	1.00	1.00	.32	.47	1.00	.54	1.03
1.76	2	.97	.00	.05	.07	1.00	1.00	.37	.51	1.00	.55	1.05
2.04	7	.96	.00	.05	.07	.99	1.00	.38	.52	1.00	.55	1.06
2.90	6	.88	.00	.06	.07	.99	1.00	.42	.55	1.00	.55	1.09
3.52	1	.83	.00	.06	.07	.99	1.00	.43	.56	1.00	.55	1.10
3.90	8	.80	.00	.06	.07	.99	1.00	.44	.56	1.00	.55	1.11
4.08	4	.77	.00	.07	.07	.99	1.00	.45	.57	1.00	.55	1.12
8.17	3	.48	.00	.10	.08	.98	1.00	.53	.62	1.00	.53	1.23
D. Adult (pool condition)												
1.02	5	.28	.01	.10	.11	.11	.29	.00	.00	.07	.11	1.03
1.76	2	.31	.01	.12	.11	.12	.32	.00	.00	.08	.12	1.05
2.04	7	.32	.01	.12	.11	.12	.32	.00	.00	.09	.12	1.06
2.90	6	.34	.01	.13	.12	.12	.34	.00	.00	.10	.13	1.09
3.52	1	.35	.01	.14	.12	.13	.34	.00	.00	.10	.13	1.10
3.90	8	.36	.01	.14	.12	.13	.35	.00	.00	.11	.14	1.11
4.08	4	.37	.01	.14	.12	.13	.35	.00	.00	.11	.14	1.12
8.17	3	.42	.01	.17	.13	.15	.39	.00	.00	.16	.16	1.23

Note: Q = Minimum flow release
C/C_o = Ratio of reservoir cost with Q to that with Q=0 (T=25 years, net water supply equals 10% of mean flow)

Table 38. Fish Suitability (GM Criterion) for the Range of Low Flow Releases

Station No. 96 ; USGS No. 05574500 ; Flat Branch near Taylorville
D.A. 276 Sq Mi ; Mean Flow 203 cfs ; Q(7,10) 0.00 cfs

Q		Suitability for Fish Number										
cfs	No.	1	2	3	4	5	6	7	8	9	avg	C/C_o
A. Juvenile (riffle condition)												
1.02	5	.00	.55	.00	.00	.27	.34	.00	.00	.00	.13	1.03
1.76	2	.00	.64	.00	.00	.29	.36	.00	.00	.00	.14	1.05
2.04	7	.01	.63	.00	.00	.30	.37	.00	.00	.00	.14	1.06
2.90	6	.02	.52	.00	.00	.31	.39	.00	.00	.00	.14	1.09
3.52	1	.02	.42	.00	.00	.31	.40	.00	.00	.00	.13	1.10
3.90	8	.01	.39	.00	.00	.32	.40	.00	.00	.00	.12	1.11
4.08	4	.01	.38	.00	.00	.32	.40	.00	.00	.00	.12	1.12
8.17	3	.00	.23	.00	.00	.35	.40	.00	.00	.00	.11	1.23
B. Adult (riffle condition)												
1.02	5	.00	.55	.00	.00	.00	.00	.00	.00	.00	.06	1.03
1.76	2	.00	.53	.00	.00	.00	.00	.00	.00	.00	.06	1.05
2.04	7	.00	.53	.00	.00	.00	.00	.00	.00	.00	.06	1.06
2.90	6	.00	.49	.00	.00	.00	.00	.00	.00	.00	.05	1.09
3.52	1	.00	.47	.00	.00	.00	.00	.00	.00	.00	.05	1.10
3.90	8	.00	.46	.00	.00	.00	.00	.00	.00	.00	.05	1.11
4.08	4	.00	.46	.00	.00	.00	.00	.00	.00	.00	.05	1.12
8.17	3	.00	.39	.00	.00	.00	.00	.00	.00	.00	.04	1.23
C. Juvenile (pool condition)												
1.02	5	.99	.00	.20	.17	1.00	1.00	.56	.69	1.00	.62	1.03
1.76	2	.98	.00	.22	.18	1.00	1.00	.61	.71	1.00	.63	1.05
2.04	7	.98	.00	.23	.18	1.00	1.00	.62	.72	1.00	.64	1.06
2.90	6	.94	.00	.24	.18	1.00	1.00	.65	.74	1.00	.64	1.09
3.52	1	.91	.00	.25	.18	1.00	1.00	.66	.75	1.00	.64	1.10
3.90	8	.89	.00	.25	.19	1.00	1.00	.67	.75	1.00	.64	1.11
4.08	4	.88	.00	.26	.19	1.00	1.00	.67	.75	1.00	.64	1.12
8.17	3	.69	.00	.31	.19	.99	1.00	.73	.79	1.00	.63	1.23
D. Adult (pool condition)												
1.02	5	.53	.11	.32	.33	.33	.46	.00	.00	.26	.26	1.03
1.76	2	.56	.10	.34	.33	.34	.48	.00	.00	.28	.27	1.05
2.04	7	.57	.09	.35	.34	.34	.49	.00	.00	.29	.27	1.06
2.90	6	.59	.09	.36	.34	.35	.50	.00	.00	.31	.28	1.09
3.52	1	.60	.09	.37	.35	.36	.50	.00	.00	.32	.29	1.10
3.90	8	.60	.09	.37	.35	.36	.51	.00	.00	.32	.29	1.11
4.08	4	.60	.08	.38	.35	.36	.51	.00	.00	.33	.29	1.12
8.17	3	.65	.07	.41	.36	.38	.54	.00	.00	.40	.31	1.23

Note: Q = Minimum flow release
C/C_o = Ratio of reservoir cost with Q to that with Q=0 (T=25 years, net water supply equals 10% of mean flow)

Table 39. Fish Suitability (MIN Criterion) for the Range of Low Flow Releases

Station No. 97 ; USGS No. 05575500 ; S. F. Sangamon River at Kincaid
D.A. 562 Sq Mi ; Mean Flow 408 cfs ; Q(7,10) 0.79 cfs

Q		Suitability for Fish Number										
cfs	No.	1	2	3	4	5	6	7	8	9	avg	C/C_o
A. Juvenile (riffle condition)												
4.13	5	.00	.19	.00	.00	.09	.13	.00	.00	.00	.05	1.08
5.30	7	.00	.13	.00	.00	.09	.14	.00	.00	.00	.04	1.11
5.65	2	.00	.11	.00	.00	.09	.14	.00	.00	.00	.04	1.11
7.50	6	.00	.08	.00	.00	.10	.14	.00	.00	.00	.04	1.15
9.00	8	.00	.06	.00	.00	.10	.15	.00	.00	.00	.03	1.18
9.80	4	.00	.05	.00	.00	.10	.15	.00	.00	.00	.03	1.19
11.30	1	.00	.04	.00	.00	.10	.15	.00	.00	.00	.03	1.22
19.60	3	.00	.02	.00	.00	.11	.16	.00	.00	.00	.03	1.37
B. Adult (riffle condition)												
4.13	5	.00	.22	.00	.00	.00	.00	.00	.00	.00	.02	1.08
5.30	7	.00	.20	.00	.00	.00	.00	.00	.00	.00	.02	1.11
5.65	2	.00	.19	.00	.00	.00	.00	.00	.00	.00	.02	1.11
7.50	6	.00	.17	.00	.00	.00	.00	.00	.00	.00	.02	1.15
9.00	8	.00	.15	.00	.00	.00	.00	.00	.00	.00	.02	1.18
9.80	4	.00	.15	.00	.00	.00	.00	.00	.00	.00	.02	1.19
11.30	1	.00	.13	.00	.00	.00	.00	.00	.00	.00	.01	1.22
19.60	3	.00	.09	.00	.00	.00	.00	.00	.00	.00	.01	1.37
C. Juvenile (pool condition)												
4.13	5	.93	.00	.10	.07	.99	1.00	.55	.63	1.00	.59	1.08
5.30	7	.89	.00	.11	.07	.99	1.00	.56	.63	1.00	.58	1.11
5.65	2	.88	.00	.11	.07	.99	1.00	.56	.63	1.00	.58	1.11
7.50	6	.80	.00	.11	.07	.99	1.00	.57	.64	1.00	.58	1.15
9.00	8	.75	.00	.11	.07	.99	1.00	.58	.64	1.00	.57	1.18
9.80	4	.72	.00	.11	.07	.99	1.00	.58	.64	1.00	.57	1.19
11.30	1	.67	.00	.11	.08	.99	1.00	.58	.64	1.00	.56	1.22
19.60	3	.48	.00	.12	.08	.98	1.00	.59	.65	1.00	.54	1.37
D. Adult (pool condition)												
4.13	5	.43	.01	.17	.13	.15	.40	.00	.00	.17	.16	1.08
5.30	7	.44	.00	.18	.14	.15	.40	.00	.00	.18	.17	1.11
5.65	2	.44	.00	.18	.14	.15	.40	.00	.00	.18	.17	1.11
7.50	6	.45	.00	.18	.14	.15	.40	.00	.00	.18	.17	1.15
9.00	8	.46	.07	.18	.14	.16	.41	.00	.00	.19	.17	1.18
9.80	4	.46	.00	.18	.14	.16	.41	.00	.00	.19	.17	1.19
11.30	1	.46	.00	.18	.14	.16	.41	.00	.00	.19	.17	1.22
19.60	3	.47	.00	.19	.14	.16	.41	.00	.00	.20	.17	1.37

Note: Q = Minimum flow release
C/C_o = Ratio of reservoir cost with Q to that with Q=0 (T=25 years, net water supply equals 10% of mean flow)

Table 40. Fish Suitability (GM Criterion) for the Range of Low Flow Releases

Station No. 97 ; USGS No. 05575500 ; S. F. Sangamon River at Kincaid
D.A. 562 Sq Mi ; Mean Flow 408 cfs ; Q(7,10) 0.79 cfs

Q		Suitability for Fish Number										
cfs	No.	1	2	3	4	5	6	7	8	9	avg	C/C_o
A. Juvenile (riffle condition)												
4.13	5	.00	.32	.00	.00	.27	.34	.00	.00	.00	.10	1.08
5.30	7	.00	.27	.00	.00	.27	.33	.00	.00	.00	.10	1.11
5.65	2	.00	.26	.00	.00	.27	.33	.00	.00	.00	.10	1.11
7.50	6	.00	.22	.00	.00	.26	.32	.00	.00	.00	.09	1.15
9.00	8	.00	.19	.00	.00	.25	.31	.00	.00	.00	.08	1.18
9.80	4	.00	.17	.00	.00	.25	.30	.00	.00	.00	.08	1.19
11.30	1	.00	.16	.00	.00	.24	.29	.00	.00	.00	.08	1.22
19.60	3	.00	.12	.00	.00	.20	.26	.00	.00	.00	.06	1.37
B. Adult (riffle condition)												
4.13	5	.00	.46	.00	.00	.00	.00	.00	.00	.00	.05	1.08
5.30	7	.00	.44	.00	.00	.00	.00	.00	.00	.00	.05	1.11
5.65	2	.00	.43	.00	.00	.00	.00	.00	.00	.00	.05	1.11
7.50	6	.00	.41	.00	.00	.00	.00	.00	.00	.00	.05	1.15
9.00	8	.00	.39	.00	.00	.00	.00	.00	.00	.00	.04	1.18
9.80	4	.00	.38	.00	.00	.00	.00	.00	.00	.00	.04	1.19
11.30	1	.00	.36	.00	.00	.00	.00	.00	.00	.00	.04	1.22
19.60	3	.00	.30	.00	.00	.00	.00	.00	.00	.00	.03	1.37
C. Juvenile (pool condition)												
4.13	5	.96	.00	.32	.19	1.00	1.00	.74	.79	1.00	.67	1.08
5.30	7	.94	.00	.33	.19	1.00	1.00	.75	.79	1.00	.67	1.11
5.65	2	.94	.00	.33	.19	1.00	1.00	.75	.79	1.00	.67	1.11
7.50	6	.90	.00	.33	.19	1.00	1.00	.75	.80	1.00	.66	1.15
9.00	8	.86	.00	.33	.19	1.00	1.00	.76	.80	1.00	.66	1.18
9.80	4	.85	.00	.33	.19	1.00	1.00	.76	.80	1.00	.66	1.19
11.30	1	.82	.00	.33	.19	1.00	1.00	.76	.80	1.00	.66	1.22
19.60	3	.69	.00	.34	.20	.99	1.00	.77	.81	1.00	.64	1.37
D. Adult (pool condition)												
4.13	5	.66	.07	.42	.37	.39	.54	.00	.00	.41	.32	1.08
5.30	7	.66	.07	.42	.37	.39	.54	.00	.00	.42	.32	1.11
5.65	2	.66	.07	.42	.37	.39	.54	.00	.00	.42	.32	1.11
7.50	6	.67	.07	.42	.37	.39	.55	.00	.00	.43	.32	1.15
9.00	8	.68	.07	.43	.37	.40	.55	.00	.00	.43	.33	1.18
9.80	4	.68	.06	.43	.37	.40	.55	.00	.00	.43	.32	1.19
11.30	1	.68	.06	.43	.37	.40	.55	.00	.00	.43	.32	1.22
19.60	3	.69	.06	.44	.37	.40	.56	.00	.00	.44	.33	1.37

Note: Q = Minimum flow release
C/C_o = Ratio of reservoir cost with Q to that with Q=0 (T=25 years, net water supply equals 10% of mean flow)

Table 41. Fish Suitability (MIN Criterion) for the Range of Low Flow Releases

Station No. 98 ; USGS No. 05576000 ; S. F. Sangamon River near Rochester
D.A. 867 Sq Mi ; Mean Flow 571 cfs ; Q(7,10) 0.84 cfs

Q		Suitability for Fish Number										
cfs	No	1	2	3	4	5	6	7	8	9	avg	C/C_o
A. Juvenile (riffle condition)												
8.00	5	.00	.11	.00	.00	.16	.22	.00	.00	.00	.05	1.09
8.10	2	.00	.11	.00	.00	.16	.22	.00	.00	.00	.05	1.09
10.27	7	.00	.09	.00	.00	.19	.25	.00	.00	.00	.06	1.12
14.41	6	.00	.05	.00	.00	.24	.31	.00	.00	.08	.08	1.17
16.20	1	.00	.04	.00	.00	.25	.33	.00	.00	.12	.08	1.19
18.20	8	.00	.04	.00	.00	.27	.35	.00	.00	.17	.09	1.21
18.90	4	.00	.03	.00	.00	.28	.36	.00	.00	.19	.10	1.22
37.80	3	.00	.01	.00	.00	.32	.39	.00	.00	.54	.14	1.43
B. Adult (riffle condition)												
8.00	5	.00	.19	.00	.00	.00	.00	.00	.00	.00	.02	1.09
8.10	2	.00	.19	.00	.00	.00	.00	.00	.00	.00	.02	1.09
10.27	7	.00	.18	.00	.00	.00	.00	.00	.00	.00	.02	1.12
14.41	6	.00	.15	.00	.00	.00	.00	.00	.00	.00	.02	1.17
16.20	1	.00	.14	.00	.00	.00	.00	.00	.00	.00	.02	1.19
18.20	8	.00	.13	.00	.00	.00	.00	.00	.00	.00	.01	1.21
18.90	4	.00	.13	.00	.00	.00	.00	.00	.00	.00	.01	1.22
37.80	3	.01	.08	.00	.00	.00	.00	.00	.00	.00	.01	1.43
C. Juvenile (pool condition)												
8.00	5	.78	.00	.35	.07	.99	1.00	.75	.74	1.00	.63	1.09
8.10	2	.78	.00	.35	.07	.99	1.00	.75	.74	1.00	.63	1.09
10.27	7	.69	.00	.51	.08	.99	1.00	.77	.76	1.00	.64	1.12
14.41	6	.52	.00	.73	.08	.99	1.00	.81	.78	1.00	.66	1.17
16.20	1	.45	.00	.79	.08	.98	1.00	.82	.79	1.00	.66	1.19
18.20	8	.42	.00	.85	.08	.98	1.00	.83	.79	1.00	.66	1.21
18.90	4	.39	.00	.86	.08	.98	1.00	.83	.80	1.00	.66	1.22
37.80	3	.16	.00	.95	.08	.95	1.00	.90	.85	.99	.65	1.43
D. Adult (pool condition)												
8.00	5	.67	.00	.30	.16	.20	.52	.26	.00	.44	.28	1.09
8.10	2	.67	.00	.30	.16	.20	.52	.26	.00	.44	.28	1.09
10.27	7	.71	.00	.34	.17	.21	.54	.42	.00	.50	.32	1.12
14.41	6	.77	.00	.43	.18	.22	.57	.62	.01	.59	.38	1.17
16.20	1	.79	.00	.46	.18	.23	.58	.65	.01	.62	.39	1.19
18.20	8	.81	.00	.51	.18	.23	.59	.69	.03	.65	.41	1.21
18.90	4	.81	.00	.53	.18	.23	.60	.71	.03	.66	.42	1.22
37.80	3	.90	.00	.90	.20	.26	.68	.86	.11	.78	.52	1.43

Note: Q = Minimum flow release
C/C_o = Ratio of reservoir cost with Q to that with Q=0 (T=25 years, net water supply equals 10% of mean flow)

Table 42. Fish Suitability (GM Criterion) for the Range of Low Flow Releases

Station No. 98 ; USGS No. 05576000 ; S. F. Sangamon River near Rochester
D.A. 867 Sq Mi ; Mean Flow 571 cfs ; Q(7,10) 0.84 cfs

Q		Suitability for Fish Number										
cfs	No.	1	2	3	4	5	6	7	8	9	avg	C/C_o
A. Juvenile (riffle condition)												
8.00	5	.00	.33	.00	.00	.35	.42	.00	.00	.00	.12	1.09
8.10	2	.00	.33	.00	.00	.35	.42	.00	.00	.00	.12	1.09
10.27	7	.00	.30	.00	.00	.37	.44	.00	.00	.00	.12	1.12
14.41	6	.00	.20	.00	.00	.38	.44	.00	.00	.26	.14	1.17
16.20	1	.00	.18	.00	.00	.38	.44	.00	.00	.32	.15	1.19
18.20	8	.00	.17	.00	.00	.38	.45	.00	.00	.39	.15	1.21
18.90	4	.00	.16	.00	.00	.38	.45	.00	.00	.41	.16	1.22
37.80	3	.00	.05	.00	.00	.38	.45	.00	.00	.66	.17	1.43
B. Adult (riffle condition)												
8.00	5	.00	.44	.00	.00	.00	.00	.00	.00	.00	.05	1.09
8.10	2	.00	.44	.00	.00	.00	.00	.00	.00	.00	.05	1.09
10.27	7	.00	.42	.00	.00	.00	.00	.00	.00	.00	.05	1.12
14.41	6	.00	.38	.00	.00	.00	.00	.00	.00	.00	.04	1.17
16.20	1	.00	.37	.00	.00	.00	.00	.00	.00	.00	.04	1.19
18.20	8	.01	.36	.00	.00	.00	.00	.00	.00	.00	.04	1.21
18.90	4	.01	.35	.00	.00	.00	.00	.00	.00	.00	.04	1.22
37.80	3	.03	.26	.00	.00	.00	.00	.00	.00	.00	.03	1.43
C. Juvenile (pool condition)												
8.00	5	.89	.00	.60	.20	1.00	1.00	.87	.86	1.00	.71	1.09
8.10	2	.89	.00	.60	.20	1.00	1.00	.87	.86	1.00	.71	1.09
10.27	7	.83	.00	.71	.20	1.00	1.00	.88	.87	1.00	.72	1.12
14.41	6	.72	.00	.85	.21	.99	1.00	.90	.88	1.00	.73	1.17
16.20	1	.68	.00	.89	.21	.99	1.00	.90	.89	1.00	.73	1.19
18.20	8	.64	.00	.92	.21	.99	1.00	.91	.89	1.00	.73	1.21
18.90	4	.63	.00	.93	.21	.99	1.00	.91	.89	1.00	.73	1.22
37.80	3	.40	.00	.97	.22	.97	1.00	.95	.92	1.00	.71	1.43
D. Adult (pool condition)												
8.00	5	.82	.00	.55	.41	.45	.62	.51	.00	.66	.45	1.09
8.10	2	.82	.00	.55	.41	.45	.62	.51	.00	.66	.45	1.09
10.27	7	.85	.00	.58	.41	.46	.63	.65	.00	.71	.48	1.12
14.41	6	.88	.00	.65	.42	.47	.65	.79	.08	.77	.52	1.17
16.20	1	.89	.00	.68	.42	.48	.66	.81	.12	.79	.54	1.19
18.20	8	.90	.00	.71	.43	.48	.66	.83	.17	.81	.55	1.21
18.90	4	.90	.00	.73	.43	.48	.67	.84	.18	.81	.56	1.22
37.80	3	.91	.00	.95	.45	.51	.72	.93	.33	.88	.63	1.43

Note: Q = Minimum flow release
C/C_o = Ratio of reservoir cost with Q to that with Q=0 (T=25 years, net water supply equals 10% of mean flow)

In the case of South Fork Sangamon River at Kincaid (drainage area 562 sq mi), the average fish preference for the riffles is about 0.04 with MIN and 0.09 with GM for the juveniles, and about 0.02 and 0.04 for the adults, for the low flow range of 4.13 to 19.60 cfs. In the pools, the juvenile fish preference is about 0.57 with MIN and 0.66 with GM, and the adult fish preference is 0.17 with MIN and 0.32 with GM, for the low flow range studied. The fish preferences are practically unaffected by change in flow within the range of 4.13 to 19.60 cfs.

For the South Fork Sangamon River near Rochester (drainage area 867 sq mi), the average fish preference for the riffles varies from 0.05 to 0.14 with MIN and from 0.12 to 0.17 with GM for the juveniles and about 0.02 with MIN and 0.04 with GM for the adults, for the low flow range of 8.00 to 37.80 cfs. In the pools, the juvenile fish preference is about 0.65 with MIN and 0.72 with GM, and the adult fish preference increases from 0.28 to 0.52 with MIN and from 0.45 to 0.63 with GM as the flow increases from 8.00 to 37.80 cfs. There is a significant increase in adult fish preference with increase in flow but there is no such effect for the juveniles in the pools.

A summary of the fish preferences at the two ends of the low flow range is given in table 43. It is evident that unless much higher flow releases are considered, it may be satisfactory to keep minimum low flow releases for stations 096 and 097 for maintenance of the pools if the water quality is not affected adversely at low flows. The adult fish preferences increase with drainage area, largely because of higher pool depths.

TABLE 43. Costs and Fish Preferences: S.F. Sangamon River Basin (Pool Condition)

	Q	ΔC			Fish number* with preference				
No.	cfs	10^6 $	†	Crit	<0.1	0.10-0.24	0.25-0.49	0.50-0.74	0.75-1.00
096	1.02	0.180	J	MIN	2,3,4		7,8		1,5,6,9
				GM	2	3,4		7,8	1,5,6,9
			A	MIN	2,7,8,9				
				GM	7,8	2	3,4,5,6,9	1	
	8.17	1.357	J	MIN	2,4	3	1	7,8	5,6,9
				GM	2	4	3	1,7	5,6,8,9
			A	MIN	2,7,8	3,4,5,9	1,6		
				GM	2,7,8		3,4,5,9	1,6	
097	4.13	0.654	J	MIN	2,4	3		7,8	1,5,6,9
				GM	2	4	3	7	1,5,6,8,9
			A	MIN	2,7,8	3,4,5,9	1,6		
				GM	2,7,8		3,4,5,9	1,6	
	19.60	2.901	J	MIN	2,4	3	1	7,8	5,6,9
				GM	2	4	3	1	5-9
			A	MIN	2,7,8	3,4,5,9	1,6		
				GM	2,7,8		3,4,5,9	1,6	
098	8.00	1.049	J	MIN	2,4		3	8	1,5,6,7,9
				GM	2	4		3	1,5-9
			A	MIN	2,8	4,5	3,7,9	1,6	
				GM	2,8		4,5	3,6,7,9	1
	37.80	4.752	J	MIN	2,4	1			3,5-9
				GM	2	4	1		3,5-9
			A	MIN	2	4,8	5	6	1,3,7,9
				GM	2		4,8	5,6	1,3,7,9

* 1 = Bluegill, 2 = Bluntnose, 3 = Carp, 4 = Channel Cat, 5 = Largemouth Bass, 6 = Smallmouth Bass, 7 = Drum, 8 = White Bass, 9 = White Crappie

† J and A denote Juvenile and Adult, respectively.

CONCLUSIONS AND SUGGESTIONS

The hydraulic geometry parameters (flow velocity and depth, V and D; flow width, W; and flow section area, A) have been derived (Singh, 1981), but only V and D are given in this report for 8 low flow releases at each of the 123 gaging stations. Methodologies have been developed for adjusting reservoir storage to allow for capacity loss from evaporation and sedimentation in the reservoir, for various design droughts and net water supply rates of 2, 5, 10 and 20 percent of mean flow. The velocity-depth domains have been analyzed for the juveniles and adults of the nine target fish: bluegill, bluntnose, carp, channel cat, largemouth bass, smallmouth bass, drum, white bass, and white crappie. The domain charts indicate that most of the fish will be in the pools and that the desirable flow environment of some fish is quite different from that of others. Information on fish preference and reservoir costs at each of the stations is included in Volume II of this report (Singh and Ramamurthy, 1981). The following conclusions are drawn from this study:

1) The suitable criterion for defining a fish suitability or preference from individual V and D preferences is somewhere between MIN and GM. The basic data, from which individual preferences are derived, can be analyzed to clarify the criterion selection.

2) C3 or the median 61-day low flow during the period May to October is the highest low flow release at each of the 123 stations, but the lowest flow release is C2 (i.e., one-half of the 31-day median low flow during the period May to October) for 83 stations, and C5 (i.e., flow at 90 percent duration using daily flows during May to October) for 40 stations.

3) The formula, $d_p = d_r + b \times$ (log of drainage area in sq mi), was used in computing the average depth in the pools. The sensitivity analysis on

the value of b shows that fish preferences for the pools with b = 0.5 are significantly low and that these preferences with b = 0.75 and b = 1.00 are not significantly different from each other. A value of 0.75 has been used in this study and it is considered to be satisfactory. However, field data need to be collected to improve the estimate.

4) The role of the pools is very important in maintaining suitable habitats for fish during low flow conditions as represented by the low flow releases C1 through C8. The role of the riffles is important in their acting as submerged dams to slow down the release of water from the pools behind them, as well as in providing greater opportunity for oxygenation because of shallow flow depths, higher velocity than in pools, and flow turbulence.

5) Generally, the fish preference along a stream increases with drainage area because of increases in pool depths with comparable flows, if other factors such as substrate, cover, and water quality remain similar.

6) Fish preferences and costs have been analyzed in detail for five basins to provide geographical, areal, and hydrologic variation. For the Little Wabash River Basin, the bluegill, carp, smallmouth bass, drum, and white crappie have about 0.5 and higher preferences in the Clay City reach at 15 cfs; for the Skillet Fork at Wayne City, an increase in flow from 0.74 to 7.78 cfs does not significantly affect the low fish preferences; and for the Carmi reach with low flow range 24-123 cfs, the bluegill, carp, largemouth bass, smallmouth bass, drum, and white crappie have about 0.5 and higher preferences with 24 cfs, though the channel cat is added to the list with 123 cfs. For the Kishwaukee River Basin, the fish preference steadily increases with an increase in low flow release over the range studied at Belvidere;

the increase is much smaller for the South Branch with less sustained low flows; and the fish preference near Perryville is practically the same for the flow range studied, i.e., 69 to 156 cfs.

For the Bay Creek Basin with small drainage area sub-basins, the average fish preferences are rather low for the low flow range studied. The sub-basins have zero flow for many days in most years. Much higher low flows than considered in this study will increase the reservoir costs tremendously. In such very low flow streams, provision of some low flow releases provides fish habitat for many fish though the preferences may vary from less than 0.1 to about 0.5. The Vermilion River Basin (draining to the Illinois River) portrays the significant increase in fish preferences with an increase in drainage area for the low flow releases considered. The increase in preference at a station is significant for minimum to mean range at Lowell, whereas at the upper two stations, the increase in preference with increase in release is rather small. Similar behavior is exhibited by the South Fork Sangamon River Basin.

The information developed in this report (both Volumes I and II) can be used to make rational decisions about the desirability of mandating minimum low flow release from a dam, considering the historical low flows, 7-day 10-year low flow, increase in variety and preference of the fish versus the costs, etc.

7) The cost versus fish preference (average as well as individual) curves provide information for a decision maker regarding trade-offs between the two objectives: maximizing fish suitability and minimizing reservoir cost.

8) The range of low flow releases studied does not satisfactorily delineate the cost-preference relationship over the entire low flow range. In some cases, this range needs to be expanded for both lower and higher flows.

In the low flow range studied in this report, in most cases, the increase in fish suitability is rather small with increase in flow; in some cases the fish suitability is independent of the flow range; and in some cases the fish suitability is negligible for the riffles.

9) For a design drought of 25 years, the minimum low flow release will last for the critical drought duration. In other years, the flows released will be higher. The reservoirs can be so regulated as to provide desirable flow release sequences (much higher than the mandatory minimum) for most of the years.

10) Low flow release criteria to preserve fish habitats will vary from one basin to another depending on the variability of the low flow regimen and hydraulic geometry of the stream.

11) The lowest flow in the low flow range (C1 through C8) is much higher than the 7-day 10-year low flow.

12) The design low flow releases are available in the first to the final year of the design drought period, T, years. However, the storage lost to sediments entrapped in the reservoir increases with years. Thus, higher low flow releases can be mandated in the beginning, and these can be reduced with the passage of years to the design values in the Tth year.

Suggestions for Future Research

1) The reaeration capacity of the riffles at different low flows as well as the dissolved oxygen, DO, levels in riffles and pools may be studied for different streams and drainage areas to determine the minimum low flow needed to maintain suitable DO levels in pools in different seasons of the year. These flows will provide seasonal low flow benchmarks and thus allow consideration of the water quality factor.

2) A number of pools may be studied to develop percentages of area with different depth intervals, the distribution of velocities in these subareas, and the quality of substrates. Modeling of this information for a stream system will help in better definition of fish preferences because of the consideration of subareas. Some fish, excluded because of average depth, may be there because of significant variation in pool depth from one place to the other.

3) The desirability of occasionally flushing out some sediment to improve the substrate may be examined from field observations and data collections.

4) The value of b in determining pool depth may be examined statistically from extensive field data. Factors which affect b are probably the stream order or drainage area, runoff characteristics, sediment characteristics, channel and land slopes, etc.

5) The question about combined preference being represented by MIN or GM, or some value between the two, may be answered by re-examining the available data collected by the Fish and Wildlife Service Group and other agencies, and by augmenting the available data, where necessary, by more field work for fish found predominantly in Illinois streams.

6) Relative weights may be developed for Illinois fish in computing the average fish preference. These weights will reflect preferences of fishermen, ecologists, commercial interests, and others for each target fish.

7) The analyses done in this report may be extended to a wider range of low flows to provide more information on fish suitability and costs to the decision maker.

The impact of damming, or regulation, of rivers on obligate riverine fishes is generally negative (Holden, 1979). Some obvious immediate impacts are the blockage of upstream and/or downstream migration, habitat alteration, changes in temperature regimen of water released, and changes in turbidity and water chemistry. Temperature effects can be moderated by providing multiple-port release mechanisms that allow flow releases from the upper water layers which are also rich in dissolved oxygen. The delayed impacts are not well understood but may be caused by changes in flow duration and suspended solid concentrations, and by the introduction of new species. The relative magnitude of impacts depends on the project purposes, the existing fisheries and flow regimen, and the severity of changes caused by the reservoir operation.

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