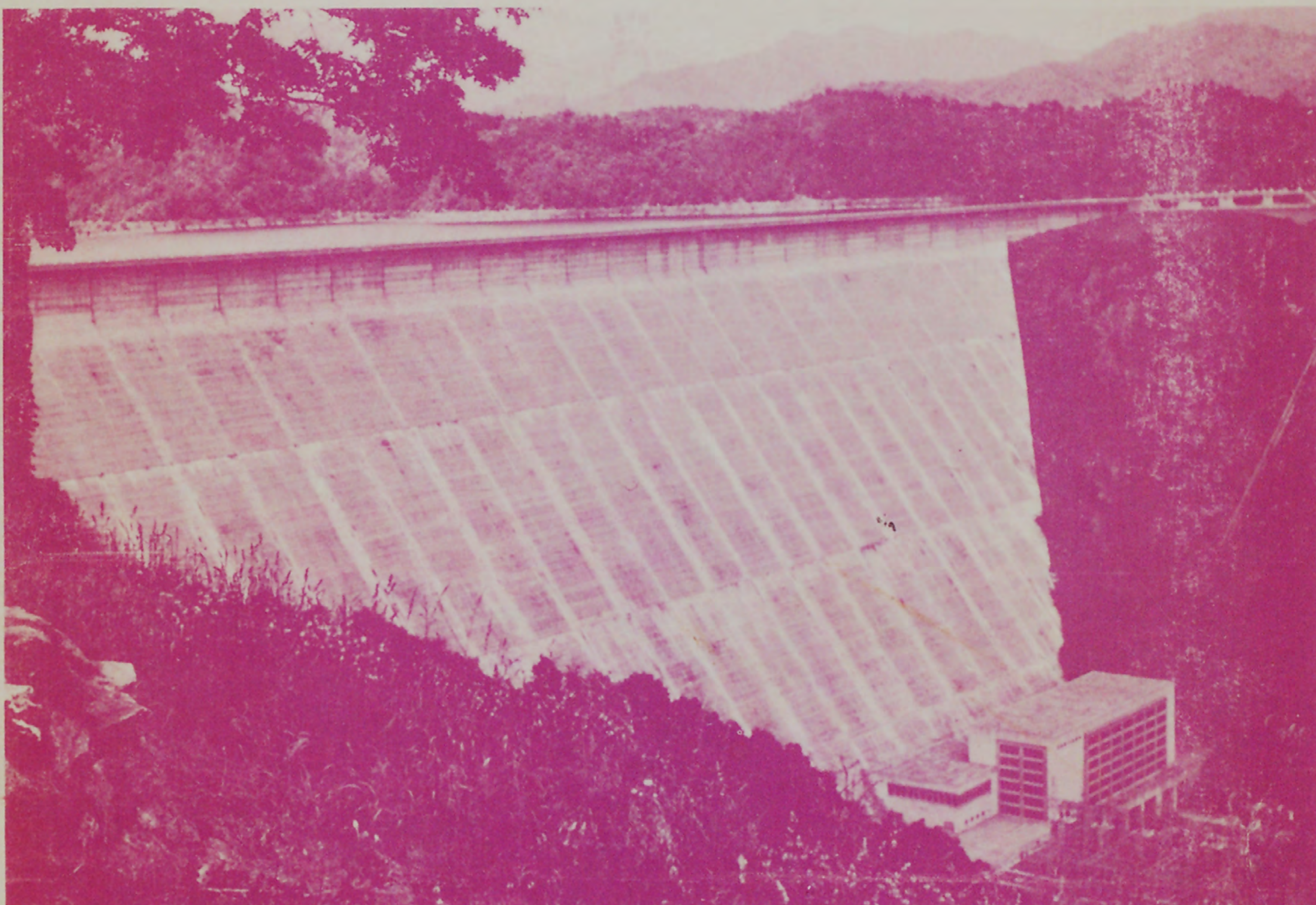
EVALUATION OF RESERVOIR SITES IN NORTH CAROLINA

Regional relations for estimating the reservoir capacity needed for a dependable water supply



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WATER RESOURCES INVESTIGATIONS 46-74

PREPARED IN COOPERATION WITH THE
NORTH CAROLINA DEPARTMENT OF NATURAL
AND ECONOMIC RESOURCES

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By

F. E. Arteaga and E. F. Hubbard

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FACTORS FOR CONVERTING ENGLISH UNITS TO INTERNATIONAL SYSTEM (SI) UNITS

The following factors may be used to convert the English units published herein to the International System of Units (SI). Subsequent reports will contain both the English and SI unit equivalents until such time that all data will be published in SI units.

Multiply English units	By	To obtain SI units
	Length	
inches (in)	25.4	millimetres (mm)
feet (ft)	.3048	metres (m)
miles (mi)	1.609	kilometres (km)
	Area	
acres	4047	square metres (m^2)
	.4047	square hectometres (hm^2)
square miles (mi^2)	2.590	square kilometres (km^2)
	Volume	
gallons (gal)	3.785	litres (l)
cubic feet (ft^3)	.02832	cubic metres (m^3)
cfs-day (ft^3/s-day)	2447	cubic metres (m^3)
	2.447×10^{-3}	cubic hectometres (hm^3)
acre-feet (acre-ft)	1233	cubic metres (m^3)
	1.233×10^{-3}	cubic hectometres (hm^3)
	Flow	
cubic feet per second (ft^3/s)	.02832	cubic metres per second (m^3/s)
cubic feet per second per square mile [$(ft^3/s)/mi^2$]	.01093	cubic metres per second per square kilometre [$(m^3/s)/km^2$]

EVALUATION OF RESERVOIR SITES IN NORTH CAROLINA

By F. E. Arteaga and E. F. Hubbard

ABSTRACT

Draft-storage-frequency relations, which show the storage required for a reservoir to furnish a specified withdrawal or draft are regionalized for four zones in the State, using the mean annual flow of the streams as an index. The differences between the zones primarily reflect differences in the variability of stream flow.

To assure the available draft will fall below 75 percent of the mean annual flow of a stream only once in 50 years on the average, a reservoir in the mountains would need a usable storage capacity of 45 percent of the mean annual runoff of the impounded stream. In comparison, reservoirs in parts of the Piedmont furnishing a draft of 75 percent of the mean annual flow must have usable storage equal to 60 percent of the mean annual runoff of the stream. In the inner Coastal Plain the storage required increases to 84 percent, and in the outer Coastal Plain to about 110 percent. These increases in storage necessary to furnish a certain draft are indicative of the general increase in streamflow variability, both seasonally and between years, that occurs from west to east in the State.

Net evaporative draft, the evaporative loss from reservoirs when annual evaporation exceeds annual precipitation, also varies from west to east. For instance, a reservoir impounding a Piedmont stream, and designed with a 5 percent chance of deficiency, will have a net evaporative draft about twice as large as a similar sized reservoir in the Coastal Plain. In the mountains, annual precipitation always exceeds evaporation because of the cooler temperatures and higher rates of precipitation.

Annual net evaporation is also proportionately smaller for large reservoirs than for small ones. On a Coastal Plain reservoir, with storage equivalent to the mean annual runoff of the stream and being drafted at 90 percent of the mean annual flow, the net evaporation for a stream with a mean annual runoff of only 500 acre-feet (0.62 cubic hectometres) is three times as great as for a stream with mean annual runoff of 100,000 acre-feet (123 cubic hectometres). Thus, one large reservoir has less evaporation loss than several small ones capable of furnishing, collectively, the same reliable draft.

Under some circumstances, sedimentation can quickly reduce the available storage in a reservoir, thus decreasing the reliable draft. Estimated sedimentation rates in the Piedmont can range from 240 acre-feet per year (0.3 cubic hectometres per year) in a severely exposed drainage basin of 10 square miles (26 square kilometres) to 0.4 acre-feet per year (493 cubic metres per year) in a wooded basin of the same size.

Seepage beneath and around a reservoir dam is normally not significant in the State. The usual engineering practices should be followed, however, to avoid locating the dam on an open or active fault, cavernous limestone, or continuous beds of sand or gravel.

INTRODUCTION

Most large cities, industries, and utilities in North Carolina depend on streams for their water supplies. When the user's needs exceed the minimum streamflow, enough storage must be provided during periods of high streamflow to sustain them during periods when streamflow is less than their demand, or draft.

A detailed hydrologic analysis is required at a proposed reservoir site to determine the minimum size reservoir having sufficient storage capacity to furnish a specified draft. The primary product of this analysis is a draft-storage relation showing, for any draft rate, the amount of storage needed at that site to maintain that draft rate. Often, some degree of reliability is associated with the draft-storage relation. For example, the relation may be computed so as to show the draft that can be equaled or exceeded in all but 2 percent of the years. In other words, the storage in the reservoir would be sufficient to furnish the required draft every year except one, on the average, in 50 years.

Figure 1 is a typical draft-storage relation. The relation can be used to determine the storage necessary to furnish any specified draft, as long as it does not exceed the long-term mean annual flow of the stream. Or, knowing the storage capacity of a proposed or existing reservoir, one may determine the reliable draft. The draft rate is expressed in percent of the mean

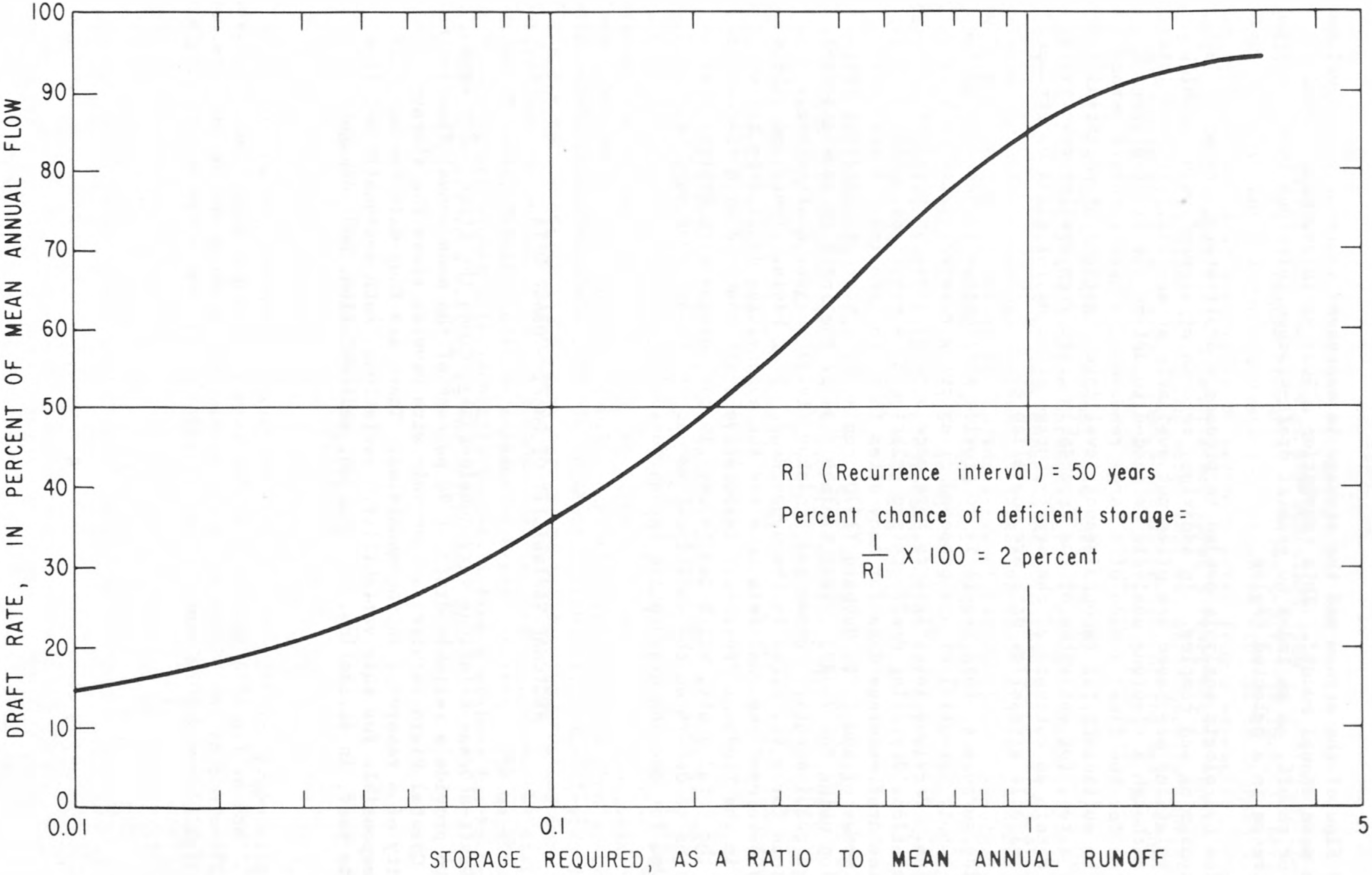

Figure 1.--Draft-storage relation for a hypothetical site.

annual flow of the stream and the storage is expressed in terms of the volume of the mean annual runoff. This convention allows us to use mean annual flow, or runoff, as an index to general draft-storage relations that apply to all streams in a selected region.

The hydrologic analysis needed to produce a draft-storage relation is time-consuming and complex. In addition, records of streamflow upon which these relations are based are often not available at specific sites of interest. Although a rigorous analysis is needed to define the draft-storage relation for the final design of a large reservoir, a less accurate method might be sufficient for reconnaissance-level investigations of potential reservoir sites, for estimates of the dependable draft from smaller reservoirs, or to obtain an estimate of the draft-storage relation for sites on streams where reliable streamflow data are unavailable.

The purpose of this report is to provide a technique for estimating the water-supply potential of any proposed or existing reservoir site in North Carolina. Previous investigators have made some progress in providing data and relations depicting draft-storage relations. A report by Goddard (1963) contains draft-storage data for many sites in North Carolina. A study by W. M. McMaster and E. F. Hubbard (1970) contained a Statewide draft-storage relation using the 7-day, 2-year minimum flow as the index to seasonal draft-storage requirements. Putnam and Lindskov (1973) present draft-storage relations for a few sites in the upper Neuse River basin. Yonts and others (1973) developed regional relations for the evaporative draft from reservoirs in the Piedmont Province. Evaporative draft combined with the demand gives the total draft, which can be used in conjunction with draft-storage relations to determine the additional amount of storage that must be provided for meeting evaporative losses during droughts.

REGIONAL VARIABILITY OF DRAFT-STORAGE DATA

Draft-storage relations vary considerably across the State. For example, to provide a reliable draft of 90 percent of the mean annual flow in the outer Coastal Plain requires a reservoir with several times the storage capacity of a reservoir in the mountains. There are four main factors that are responsible for this variability: variations, both seasonally and from year to year, in streamflow, evaporation, sedimentation, and seepage.

Streamflow

It is apparent that the greater the sustained flow of a stream, the smaller the reservoir needed to satisfy a given draft. In fact, if streamflow is consistently above the draft rate, then no storage is necessary. On the other hand, it is impossible to get more water from a stream than the long-term mean annual flow--no matter how large a reservoir is constructed. Considering costs, evaporation, and other factors, it is usually impractical to consider a draft rate larger than about 90 percent of the mean annual flow. Figure 2 depicts the range in mean annual flows across the State.

While the long-term mean annual flow controls the ultimate yield of a reservoir, the variation in flow between years is of major importance in determining the necessary storage capacity of a reservoir. If flows are extremely variable from year to year, a large amount of storage is necessary to impound sufficient streamflow during years of excess flow to provide the required draft during years of deficient flow. Conversely, if the year to year variability is small, a smaller amount of storage is sufficient to maintain the required draft. Storage requirements which include this type of variability are referred to as carryover storage.

The draft-storage relation depends also on seasonal variations in streamflow. This within-year variation is determined by frequency analysis of daily flow values. Data derived from this analysis permit the computation of storage requirements for draft rates usually below 50 percent of the mean annual flow (referred to as seasonal storage).

The 7-day, 2-year low flow may be used as an index to seasonal variations of streamflow. The lowest mean flow for 7 consecutive days is expected to be less than the 7-day, 2-year flow in 50 percent of the years, on the average. A stream with well-sustained flows, indicated by a relatively high 7-day, 2-year low flow per square mile, has less variable flow than a stream with poorly sustained low flows. In column 8 of table 1, 7-day, 2-year low flows are tabulated for 142 streams across the State. These values were derived for the period of record ending in 1968. Figure 3 shows the distribution of 7-day, 2-year flows for streams in North Carolina. The magnitude of discharge per square mile generally increases from a minimum in the eastern part of the State to a maximum in the westernmost part.

Evaporation

Reservoirs with large water surfaces can have significant evaporation losses. Annual lake evaporation ranges from 31 inches (787 mm) in the western part of the State to as much as 42 inches (1,070 mm) in the southeastern part of the State (Kohler and others, 1959). Mean annual precipitation

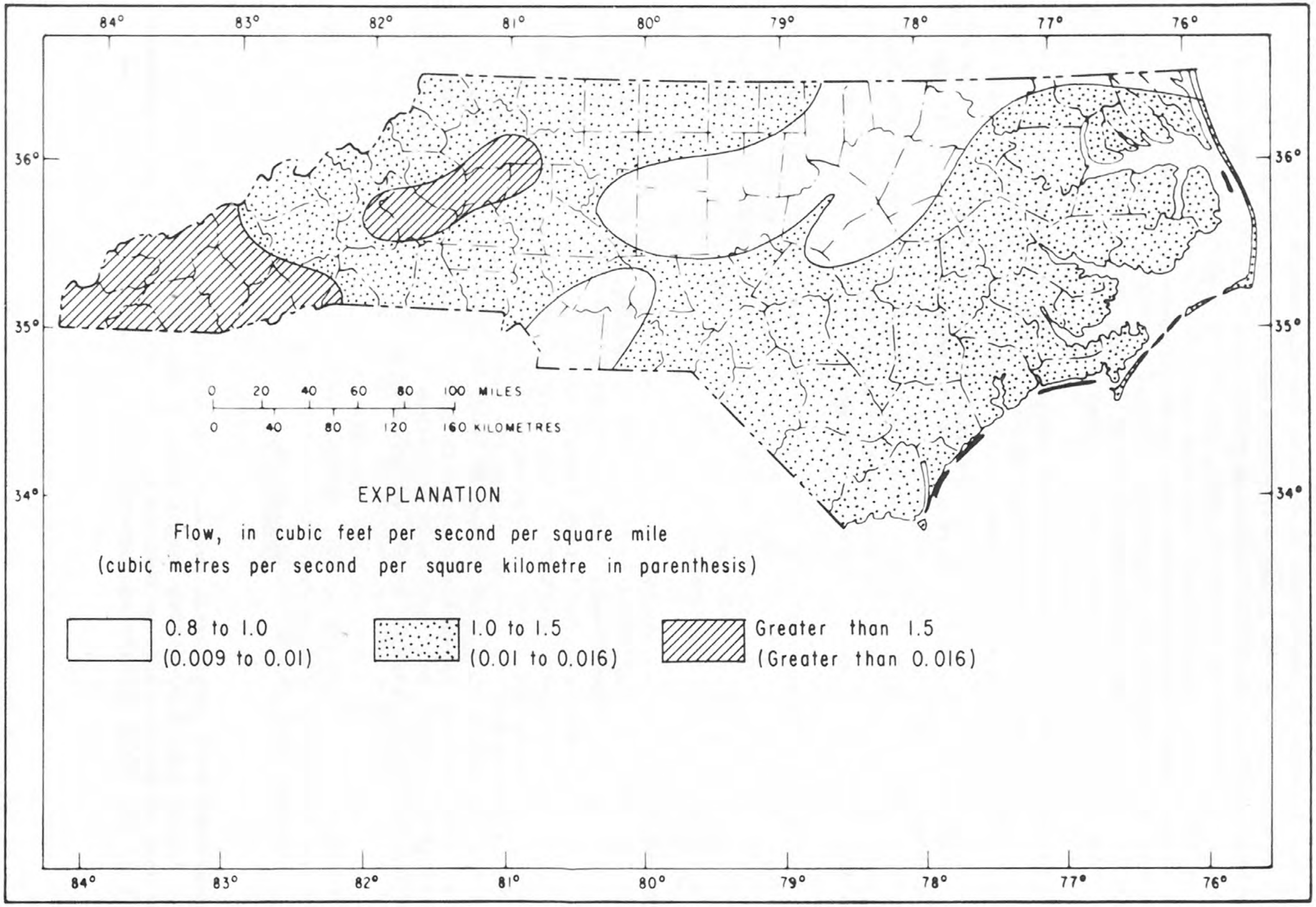

Figure 2.--Range in mean annual flow of streams in North Carolina.

Table showing draft-storage relations at long-term stream-gaging stations begins on next page

Table 1.--Draft-storage relations at

Station number	Station name	Drainage area (mi^2)	Period of record	Mean flow (ft^3/s)	Mean flow, ($\frac{ft^3/s}{mi^2}$)	Mean annual runoff (1,000 ac-ft)
02053200	Potecasi Creek near Union	191	1959-68 10 yrs	227	1.19	164
02053500	Ahoskie Creek at Ahoskie	57	1951-62 12 yrs	64	1.12	46
02070500	Mayo River near Price	260	1930-68 38 yrs	314	1.21	227
02071000	Dan River near Wentworth	1,050	1941-68 27 yrs	1160	1.10	839
02071500	Dan River at Leaksville	1,150	1930-49 14 yrs	1300	1.13	940
02081500	Tar River near Tar River	167	1940-68 28 yrs	149	.89	108
02081800	Cedar Creek near Louis-burg	47.8	1957-68 11 yrs	50	1.05	36
02082000	Tar River near Nashville	701	1929-68 39 yrs	726	1.04	525
02082500	Sapony Creek near Nashville	64.8	1951-68 17 yrs	64.4	.99	47
02083000	Fishing Creek near Enfield	521	1927-68 41 yrs	485	.93	351
02083500	Tar River at Tarboro	2,140	1897-1900 1932-68 41 yrs	2241	1.05	1621
02083800	Conetoe Creek near Bethel	78.1	1957-68 11 yrs	88	1.12	63

long-term stream-gaging stations

7-day, 2-year low flow, (ft³/s)	Percent chance of deficiency	Draft rate, in percent of mean flow									
		95	90	80	70	60	50	40	30	20	10
		Storage required, expressed as a ratio to the mean annual runoff									
2.8	2	2.63	1.55	0.86	0.58	0.36	0.21	0.16	0.11	0.06	0.03
	5	1.97	1.19	.72	.46	.29	.20	.15	.10	.06	.02
	10	1.38	.96	.57	.36	.23	.18	.14	.08	.05	.02
0	2	3.08	1.76	1.21	.85	.58	.41	.25	.15	.10	.05
	5	3.21	2.13	1.29	.90	.63	.40	.27	.14	.10	.04
	10	2.08	1.54	1.01	.69	.49	.31	.19	.14	.09	.04
113	2	1.69	1.10	.68	.46	.28	.13	.04	.01	0	0
	5	1.29	.88	.54	.33	.16	.06	.02	.02	0	0
	10	.91	.66	.39	.19	.08	.05	.02	0	0	0
350	2	1.89	1.10	.61	.36	.17	.10	.05	.03	0	0
	5	1.40	.84	.46	.23	.11	.07	.04	.02	0	0
	10	1.01	.69	.38	.19	.09	.06	.03	.01	0	0
381	2	1.53	.91	.50	.29	.16	.11	.06	.03	.01	0
	5	1.12	.69	.39	.20	.14	.09	.04	.02	0	0
	10	.83	.57	.32	.16	.12	.07	.03	.01	0	0
2.2	2	3.23	2.00	1.02	.67	.43	.26	.18	.13	.08	.03
	5	2.48	1.47	.85	.54	.35	.22	.17	.12	.07	.03
	10	1.75	1.16	.65	.43	.28	.21	.16	.11	.06	.02
11	2	2.64	1.70	1.00	.72	.50	.33	.18	.03	.02	0
	5	1.86	1.24	.78	.53	.33	.18	.07	.03	0	0
	10	1.32	.93	.59	.37	.20	.10	.05	.02	0	0
88	2	3.63	2.26	1.31	.89	.60	.38	.23	.08	.04	.01
	5	2.38	1.64	.98	.67	.44	.25	.13	.06	.03	0
	10	1.61	1.20	.78	.50	.31	.16	.09	.05	.02	0
.43	2	3.23	2.01	1.03	.68	.44	.27	.19	.14	.09	.04
	5	2.49	1.48	.85	.55	.36	.23	.18	.13	.08	.03
	10	1.76	1.17	.66	.44	.29	.22	.17	.12	.07	.03
60	2	2.80	1.79	1.07	.74	.49	.32	.19	.09	.04	.01
	5	1.91	1.34	.82	.57	.38	.22	.13	.08	.04	.01
	10	1.33	1.00	.65	.42	.24	.15	.10	.06	0	0
254	2	2.80	1.79	1.08	.74	.50	.33	.19	.10	.05	.02
	5	1.91	1.34	.82	.57	.38	.22	.13	.08	.04	.01
	10	1.33	1.01	.66	.43	.25	.16	.11	.06	.03	0
5.7	2	3.23	2.01	1.03	.67	.43	.25	.17	.12	.07	.02
	5	2.48	1.47	.84	.53	.34	.20	.15	.10	.05	.01
	10	1.75	1.16	.64	.42	.26	.18	.13	.08	.04	.01

Table 1.--Draft-storage relations at

Station number	Station name	Drainage area (mi^2)	Period of record	Mean flow (ft^3/s)	Mean flow, ($\frac{ft^3/s}{mi^2}$)	Mean annual runoff (1,000 ac-ft)
02084500	Herring Run near Washington	15	1951-69 18 yrs	11	0.71	7.72
02085000	Eno River at Hillsborough	66.5	1928-68 40 yrs	63	.95	46
02085500	Flat River at Bahama	150	1926-68 42 yrs	139	.93	101
02086000	Dial Creek near Bahama	4.7	1926-68 42 yrs	4.3	.91	3.1
02086500	Flat River at Dam near Bahama	171	1928-66 38 yrs	150	.88	109
02087000	Neuse River near Northside	526	1928-68 40 yrs	516	.98	372
02087500	Neuse River near Clayton	1,140	1928-68 40 yrs	1197	1.05	866
02088000	Middle Creek near Clayton	80.7	1941-68 27 yrs	95	1.18	69
02088500	Little River near Princeton	229	1931-68 37 yrs	260	1.13	188
02089000	Neuse River near Coldsboro	2,390	1931-68 37 yrs	2520	1.05	1822
02089500	Neuse River at Kinston	2,690	1931-68 37 yrs	2890	1.07	2089
02090500	Contentnea Creek near Wilson	236	1931-54 23 yrs	230	.97	166

long-term stream-gaging stations--Continued

7-day, 2-year low flow, (ft^3/s)	Percent chance of deficiency	Draft rate, in percent of mean flow									
		95	90	80	70	60	50	40	30	20	10
		Storage required, expressed as a ratio to the mean annual runoff									
0.85	2	3.48	2.21	1.34	0.97	0.72	0.54	0.39	0.23	0.08	0.03
	5	2.39	1.62	1.01	.73	.51	.32	.18	.07	.03	.01
	10	1.61	1.18	.78	.55	.35	.19	.14	.09	.04	0
4.6	2	2.80	1.79	1.08	.75	.51	.34	.21	.12	.07	.02
	5	1.91	1.34	.83	.57	.39	.23	.15	.10	.05	.02
	10	1.33	1.01	.66	.44	.26	.18	.13	.08	.04	.01
6	2	2.77	1.79	1.07	.79	.56	.41	.27	.13	.08	.03
	5	1.95	1.30	.84	.59	.41	.28	.16	.11	.06	.02
	10	1.37	.98	.65	.45	.29	.20	.15	.10	.05	.02
.37	2	2.80	1.79	1.08	.75	.51	.34	.22	.13	.08	.03
	5	1.91	1.34	.83	.58	.40	.25	.17	.12	.07	.02
	10	1.33	1.01	.67	.45	.28	.20	.15	.10	.05	.02
4	2	2.77	1.79	1.07	.79	.57	.42	.29	.14	.09	.04
	5	1.95	1.31	.84	.60	.42	.28	.18	.13	.08	.03
	10	1.37	.98	.66	.46	.30	.22	.17	.12	.07	.03
31	2	2.80	1.79	1.08	.75	.51	.34	.23	.13	.08	.03
	5	1.91	1.34	.83	.58	.40	.24	.16	.11	.06	.02
	10	1.33	1.01	.67	.45	.28	.19	.14	.09	.04	.01
153	2	2.43	1.56	.95	65	.45	.29	.15	.08	.03	0
	5	1.69	1.20	.74	.51	.33	.17	.11	.07	.03	0
	10	1.21	.91	.60	.38	.23	.18	.09	.05	.02	0
7.2	2	2.80	1.79	1.07	.74	.50	.33	.20	.11	.06	.02
	5	1.91	1.33	.82	.57	.38	.22	.14	.09	.04	.01
	10	1.32	1.00	.65	.42	.25	.16	.11	.06	.03	.01
20	2	3.60	2.24	1.13	.70	.44	.25	.15	.10	.05	.02
	5	2.79	1.63	.90	.56	.34	.19	.14	.09	.04	.01
	10	1.87	1.25	.69	.44	.26	.17	.12	.07	.04	.01
302	2	2.92	1.76	.92	.59	.36	.19	.13	.08	.04	.01
	5	2.21	1.32	.76	.46	.28	.16	.11	.06	.03	0
	10	1.52	1.04	.58	.36	.20	.14	.09	.05	.02	0
427	2	2.92	1.76	.93	.59	.35	.18	.12	.07	.03	.01
	5	2.21	1.32	.76	.46	.27	.15	.10	.06	.02	0
	10	1.52	1.04	.57	.35	.19	.13	.08	.05	.02	0
5.4	2	3.98	2.51	1.26	.78	.49	.30	.18	.13	.08	.03
	5	3.11	1.81	.99	.61	.40	.24	.17	.12	.06	.03
	10	2.14	1.36	.75	.48	.30	.19	.14	.09	.05	.02

Table 1.--Draft-storage relations at

Station number	Station name	Drainage area (mi^2)	Period of record	Mean flow (ft^3/s)	Mean flow, ($\frac{ft^3/s}{mi^2}$)	Mean annual runoff (1,000 ac-ft)
02091000	Nahunta Swamp near Shine	77.6	1955-68 13 yrs	87	1.12	63
02091500	Contentnea Creek at Hookerton	729	1930-68 38 yrs	766	1.05	554
02091700	Little Contentnea Creek near Farmville	93.3	1957-68 11 yrs	120	1.29	87
02092000	Swift Creek near Vance-boro	182	1951-63 12 yrs	189	1.04	137
02092500	Trent River near Trenton	168	1952-68 16 yrs	197	1.17	143
02093000	New River near Gum Branch	74.5	1950-68 18 yrs	108	1.45	78
02093500	Haw River near Benaja	168	1929-68 39 yrs	154	.92	111
02093800	Reedy Fork near Oak Ridge	19.9	1956-68 12 yrs	21.7	1.09	16
02094000	Horsepen Creek at Battle Ground	15.9	1926-59 33 yrs	14.8	.93	11
02094500	Reedy Fork nr. Gibson-ville	133	1929-68 39 yrs	104	.78	75
02096700	Big Alamance Creek near Elon College	116	1958-68 10 yrs	106	.91	77
02097000	Haw River near Pittsboro	1,310	1929-68 39 yrs	1220	.93	882

long-term stream-gaging stations--Continued

7-day, 2-year low flow, (ft^3/s)	Percent chance of deficiency	Draft rate, in percent of mean flow									
		95	90	80	70	60	50	40	30	20	10
		Storage required, expressed as a ratio to the mean annual runoff									
10	2	2.93	1.76	0.93	0.60	0.37	0.21	0.15	0.10	0.05	0.02
	5	2.21	1.32	.76	.46	.27	.15	.08	.05	.04	.01
	10	1.52	1.05	.59	.37	.21	.15	.10	.05	.02	0
74	2	3.49	2.18	1.27	.86	.60	.38	.24	.11	.06	.02
	5	2.29	1.58	.96	.66	.44	.27	.15	.09	.04	.01
	10	1.55	1.17	.76	.49	.30	.16	.11	.06	.03	0
2.9	2	2.93	1.77	.94	.61	.38	.23	.17	.12	.07	.02
	5	2.22	1.33	.78	.49	.31	.20	.15	.10	.05	.02
	10	1.52	1.05	.60	.38	.22	.17	.12	.08	.04	.01
3.9	2	5.38	3.07	1.76	1.20	.88	.71	.56	.41	.23	.12
	5	2.96	2.06	1.28	.96	.71	.52	.36	.23	.09	.04
	10	1.90	1.44	.97	.70	.49	.33	.17	.12	.08	.02
5.5	2	3.25	2.07	1.25	.92	.68	.50	.36	.21	.09	.04
	5	2.25	1.52	.97	.70	.50	.33	.20	.12	.07	.02
	10	1.53	1.12	.75	.53	.36	.22	.15	.10	.05	.02
7.9	2	2.93	1.77	.94	.61	.38	.22	.16	.11	.06	.02
	5	2.22	1.33	.77	.48	.29	.18	.13	.08	.04	.01
	10	1.52	1.05	.59	.37	.21	.15	.10	.06	.03	.01
27	2	1.89	1.22	.75	.52	.33	.19	.09	.06	.02	0
	5	1.39	.97	.61	.41	.23	.13	.08	.05	.02	0
	10	1.00	.74	.47	.27	.16	.11	.07	.03	.01	0
5	2	2.10	1.24	.68	.41	.20	.09	.04	.01	0	0
	5	1.56	.94	.53	.29	.13	.08	.03	.01	0	0
	10	1.11	.74	.42	.22	.11	.06	.02	0	0	0
2.5	2	1.71	1.00	.58	.37	.21	.15	.10	.04	.01	0
	5	1.25	.78	.45	.26	.18	.13	.08	.04	.01	0
	10	.92	.62	.36	.19	.15	.10	.06	.03	.01	0
8.9	2	2.65	1.72	1.02	.75	.54	.37	.23	.10	.05	.02
	5	1.87	1.25	.80	.55	.37	.22	.13	.08	.04	.01
	10	1.32	.94	.61	.40	.24	.16	.11	.06	.03	0
6	2	2.77	1.79	1.06	.78	.55	.39	.24	.09	.04	.01
	5	1.95	1.30	.83	.57	.39	.24	.13	.08	.03	.01
	10	1.37	.97	.64	.43	.26	.17	.12	.06	.03	.01
98	2	2.30	1.49	.91	.63	.43	.27	.14	.08	.04	.01
	5	1.62	1.15	.71	.48	.31	.17	.11	.07	.03	.01
	10	1.16	.87	.56	.35	.19	.14	.09	.06	.03	0

Table 1.--Draft-storage relations at

Station number	Station name	Drainage area (mi^2)	Period of record	Mean flow (ft^3/s)	Mean flow, ($\frac{ft^3/s}{mi^2}$)	Mean annual runoff (1,000 ac-ft)
02098500	West Fork Deep River near High Point	32.1	1924-66 42 yrs	31.5	0.98	23
02099000	East Fork Deep River near High Point	14.7	1929-68 39 yrs	14.9	1.01	11
02099500	Deep River near Randle-man	124	1929-68 39 yrs	119	.96	86
02100500	Deep River at Ramseur	346	1924-68 44 yrs	341	.99	247
02101000	Bear Creek at Robbins	134	1940-68 28 yrs	145	1.08	105
02102000	Deep River at Moncure	1,410	1931-68 37 yrs	1421	1.00	1027
02103000	Little River at Man-chester	348	1939-50 11 yrs	432	1.24	312
02103500	Little River at Linden	460	1930-68 38 yrs	560	1.21	405
02104000	Cape Fear River at Fayetteville	4370	1890-1917 1929-40 38 yrs	4744	1.08	3431
02104500	Rockfish Creek near Hope Mills	284	1930-54 24 yrs	377	1.32	273
02105500	Cape Fear River at W.O. Huske Lock near Tar-heel	4,810	1938-68 30 yrs	4904	1.01	3546
02105900	Hood Creek near Leland	21.6	1957-68 11 yrs	34	1.58	25

long-term stream-gaging stations--Continued

7-day, 2-year low flow, (ft^3/s)	Percent chance of deficiency	Draft rate, in percent of mean flow									
		95	90	80	70	60	50	40	30	20	10
		Storage required, expressed as a ratio to the mean annual runoff									
4.3	2	1.54	0.92	0.53	0.33	0.22	0.16	0.11	0.06	0.02	0
	5	1.12	.71	.42	.25	.19	.13	.08	.05	.02	0
	10	.83	.58	.35	.20	.16	.11	.07	.04	.01	0
3	2	1.89	1.22	.75	.52	.32	.18	.08	.04	.02	0
	5	1.39	.97	.61	.40	.23	.12	.07	.03	0	0
	10	1.00	.74	.47	.27	.16	.11	.06	.02	0	0
12	2	2.19	1.41	.88	.62	.41	.27	.14	.09	.04	.01
	5	1.58	1.11	.68	.47	.30	.17	.12	.07	.03	0
	10	1.13	.84	.55	.34	.20	.15	.10	.05	.02	0
26	2	2.37	1.41	.78	.51	.31	.19	.14	.09	.04	.01
	5	1.83	1.07	.64	.39	.23	.17	.12	.07	.03	.01
	10	1.25	.87	.51	.31	.20	.15	.10	.06	.03	0
6.4	2	2.66	1.73	1.04	.77	.56	.40	.26	.10	.05	.02
	5	1.87	1.26	.80	.56	.37	.23	.13	.08	.04	.02
	10	1.33	.95	.62	.41	.26	.17	.12	.07	.04	.01
71	2	2.55	1.64	.99	.69	.47	.31	.17	.10	.05	.02
	5	1.77	1.25	.78	.53	.36	.21	.14	.09	.04	.02
	10	1.25	.94	.62	.41	.24	.17	.12	.07	.04	.01
75	2	2.19	1.44	.84	.62	.43	.28	.13	.08	.03	0
	5	1.59	1.04	.67	.45	.26	.14	.09	.04	0	0
	10	1.15	.80	.49	.19	.15	.11	.07	.04	0	0
86	2	2.93	1.76	.93	.59	.35	.18	.11	.06	.02	0
	5	2.22	1.32	.75	.45	.25	.13	.08	.04	0	0
	10	1.52	1.04	.57	.35	.18	.11	.06	.03	0	0
625	2	2.37	1.41	.78	.50	.30	.17	.11	.07	.03	.01
	5	1.83	1.07	.63	.38	.22	.15	.10	.05	.01	0
	10	1.24	.86	.50	.29	.17	.12	.07	.04	.05	0
142	2	1.90	1.10	.61	.35	.10	.06	.01	0	0	0
	5	1.40	.84	.45	.21	.07	.04	.01	0	0	0
	10	1.01	.69	.37	.16	.05	.03	.01	0	0	0
675	2	2.37	1.40	.78	.50	.29	.16	.11	.06	.02	0
	5	1.83	1.07	.63	.38	.21	.14	.09	.05	.02	0
	10	1.24	.86	.50	.29	.17	.12	.07	.04	0	0
.30	2	3.01	1.92	1.15	.83	.60	.42	.26	.11	.04	.02
	5	2.10	1.40	.88	.62	.42	.26	.12	.07	.04	.02
	10	1.44	1.04	.67	.44	.25	.12	.09	.06	.04	.01

Table 1.--Draft-storage relations at

Station number	Station name	Drainage area (mi^2)	Period of record	Mean flow (ft^3/s)	Mean flow, ($\frac{ft^3/s}{mi^2}$)	Mean annual runoff (1,000 ac-ft)
02106000	Little Coharie Creek near Roseboro	96.4	1951-68 17 yrs	111	1.16	81
02106500	Black River near Tomahawk	680	1952-68 16 yrs	746	1.10	540
02107000	South River near Parkersburg	382	1952-68 16 yrs	418	1.09	302
02107500	Colly Creek near Kelly	103	1951-66 15 yrs	110	1.07	80
02108000	Northeast Cape Fear River near Chinquapin	600	1941-68 27 yrs	696	1.16	503
02108500	Rockfish Creek near Wallace	64	1956-68 12 yrs	92	1.44	67
02109500	Waccamaw River at Free-land	706	1940-68 28 yrs	671	.95	485
02111000	Yadkin River at Patterson	27	1940-68 28 yrs	46	1.61	33
02111500	Reddies River at North Wilkesboro	93.9	1940-68 28 yrs	134 134	1.42 1.42	97 97
02112000	Yadkin River at Wilkes-boro	493	1904-08 1921-61 46 yrs	800	1.63	579
02112500	Fisher River near Dobson	109	1921-32 11 yrs	161	1.47	116
02113000	Fisher River near Copeland	121	1932-68 36 yrs	177	1.46	128

long-term stream-gaging stations--Continued

7-day, 2-year low flow, (ft^3/s)	Percent chance of deficiency	Draft rate, in percent of mean flow									
		95	90	80	70	60	50	40	30	20	10
		Storage required, expressed as a ratio to the mean annual runoff									
7.6	2	3.23	2.00	1.02	0.66	0.42	0.23	0.15	0.11	0.06	0.02
	5	2.48	1.47	.83	.52	.32	.18	.13	.08	.04	.01
	10	1.75	1.15	.64	.41	.24	.16	.11	.06	.03	.01
74	2	3.23	2.00	1.02	.66	.42	.24	.16	.11	.06	.02
	5	2.48	1.47	.84	.52	.33	.19	.14	.09	.04	.01
	10	1.75	1.15	.64	.41	.24	.16	.11	.06	.03	.01
23	2	3.23	2.00	1.03	.67	.43	.26	.18	.13	.08	.03
	5	2.48	1.47	.85	.54	.35	.21	.16	.11	.06	.02
	10	1.75	1.16	.65	.43	.26	.19	.14	.09	.05	.02
1.2	2	3.98	2.52	1.27	.79	.50	.32	.20	.15	.10	.05
	5	3.11	1.81	1.00	.63	.41	.25	.19	.14	.09	.04
	10	2.14	1.37	.77	.51	.33	.23	.18	.13	.08	.03
32	2	3.35	2.10	1.24	.86	.60	.39	.25	.13	.08	.02
	5	2.22	1.54	.94	.66	.45	.28	.16	.11	.06	.02
	10	1.52	1.13	.75	.49	.30	.18	.12	.07	.04	.01
3.6	2	2.28	1.50	.87	.63	.43	.27	.12	.06	.03	.01
	5	1.65	1.08	.68	.45	.27	.12	.08	.05	.03	.01
	10	1.20	.84	.53	.32	.15	.11	.08	.04	.02	.01
16	2	6.38	3.86	1.77	1.04	.65	.40	.23	.14	.10	.05
	5	6.18	2.64	1.34	.82	.53	.32	.18	.14	.09	.04
	10	2.93	1.84	1.01	.64	.41	.25	.17	.12	.07	.03
15	2	2.19	1.40	.86	.59	.37	.22	.08	.03	0	0
	5	1.57	1.10	.66	.43	.25	.10	.05	.02	0	0
	10	1.11	.82	.51	.28	.12	.08	.03	.01	0	0
56	2	1.70	1.08	.64	.41	.23	.07	.03	.01	0	0
	5	1.24	.81	.48	.27	.10	.06	.02	0	0	0
	10	.93	.64	.35	.14	.05	.03	.01	0	0	0
316	2	2.61	1.52	.81	.50	.26	.09	.04	.01	0	0
	5	1.96	1.16	.67	.39	.19	.08	.03	.07	0	0
	10	1.36	.92	.49	.25	.08	.05	.02	0	0	0
52	2	2.10	1.24	.69	.43	.22	.12	.07	.03	0	0
	5	1.57	.94	.54	.27	.14	.09	.04	.02	0	0
	10	1.57	1.08	.68	.37	.17	.06	.03	.01	0	0
61	2	1.70	1.08	.64	.42	.25	.09	.05	.02	0	0
	5	1.25	.81	.48	.27	.10	.07	.03	.01	0	0
	10	.94	.65	.37	.17	.08	.05	.02	0	0	0

Table 1.--Draft-storage relations at

Station number	Station name	Drainage area (mi^2)	Period of record	Mean flow (ft^3/s)	Mean flow, ($\frac{ft^3/s}{mi^2}$)	Mean annual runoff (1,000 ac-ft)
02115500	Forbush Creek near Yadkinville	22	1941-68 27 yrs	23	1.06	17
02116500	Yadkin River at Yadkin College	2,280	1929-61 32 yrs	2899	1.27	1373
02117500	Rocky Creek at Turnersburg	102	1941-68 27 yrs	113	1.11	82
02118000	South Yadkin River near Mocksville	313	1939-68 29 yrs	325	1.04	235
02118500	Hunting Creek near Harmony	153	1952-68 16 yrs	192	1.25	139
02119000	South Yadkin River at Cooleemee	569	1929-65 36 yrs	639	1.12	462
02119400	Third Creek Subwatershed No. 7A near Stony Point	4.8	1957-68 11 yrs	6.54	1.36	4.728
02120500	Third Creek at Cleveland	87.4	1941-68 27 yrs	92	1.05	67
02121000	Yadkin River near Salisbury	3,470	1896-1927 31 yrs	4920	1.42	3558
02121500	Abbotts Creek at Lexington	174	1941-57 16 yrs	159	.91	115
02122500	Yadkin River at High Rock	4,000	1943-61 18 yrs	4640	1.16	3354
02123500	Uwharrie River near Eldorado	347	1939-68 29 yrs	326	.93	236

long-term stream-gaging stations--Continued

7-day, 2-year low flow, (ft^3/s)	Percent chance of deficiency	Draft rate, in percent of mean flow									
		95	90	80	70	60	50	40	30	20	10
		Storage required, expressed as a ratio to the mean annual runoff									
5.8	2	2.36	1.39	.75	.46	.25	.11	.07	.04	.01	0
	5	1.82	1.06	.60	.34	.17	.09	.06	.03	0	0
	10	1.23	.85	.47	.25	.12	.08	.04	.02	0	0
1060	2	1.69	.98	.54	.31	.13	.09	.05	.02	0	0
	5	1.24	.75	.41	.20	.11	.07	.03	.01	0	0
	10	.90	.59	.30	.11	.08	.05	.02	0	0	0
39	2	2.09	1.23	.67	.41	.20	.09	.05	.02	0	0
	5	1.56	.93	.52	.26	.10	.07	.04	.01	0	0
	10	1.11	.74	.42	.21	.10	.06	.02	.01	0	0
107	2	2.10	1.24	.68	.42	.21	.10	.05	.02	0	0
	5	1.56	.94	.53	.28	.12	.08	.04	.01	0	0
	10	1.11	.73	.40	.19	.07	.05	.03	.01	0	0
64	2	2.62	1.53	.82	.51	.27	.10	.06	.02	0	0
	5	1.96	1.16	.67	.39	.20	.09	.04	.01	0	0
	10	1.36	.93	.52	.29	.11	.09	.03	.01	0	0
190	2	2.10	1.23	.67	.41	.19	.08	.05	.02	0	0
	5	1.56	.94	.53	.29	.13	.08	.04	.02	0	0
	10	1.11	.75	.42	.22	.11	.07	.03	.01	0	0
-	2	2.10	1.23	.66	.40	.18	.06	.02	.01	0	0
	5	1.56	.93	.51	.26	.09	.05	.02	.01	0	0
	10	1.11	.73	.40	.19	.07	.04	.01	.01	0	0
29	2	2.36	1.39	.75	.46	.24	.10	.05	.02	0	0
	5	1.82	1.06	.60	.33	.17	.09	.04	.01	0	0
	10	1.23	.85	.47	.25	.12	.08	.03	.01	0	0
1580	2	2.09	1.23	.67	.41	.19	.08	.03	.01	0	0
	5	1.56	.93	.52	.26	.10	.06	.02	0	0	0
	10	1.11	.74	.41	.20	.08	.05	.02	0	0	0
9.0	2	2.62	1.05	.66	.45	.30	.19	.14	.09	.05	.01
	5	1.20	.80	.51	.34	.22	.17	.12	.07	.04	.01
	10	.91	.65	.41	.25	.20	.15	.10	.06	.03	0
1360	2	2.10	1.24	.68	.41	.20	.09	.05	.02	0	0
	5	1.56	.94	.52	.27	.11	.07	.03	.01	0	0
	10	1.11	.74	.41	.20	.08	.05	.02	.01	0	0
18	2	2.63	1.55	.86	.57	.35	.21	.16	.11	.06	.02
	5	1.97	1.18	.71	.45	.28	.19	.14	.09	.04	.02
	10	1.38	.95	.56	.34	.22	.17	.12	.07	.04	.02

Table 1.--Draft-storage relations at

Station number	Station name	Drainage area (mi^2)	Period of record	Mean flow (ft^3/s)	Mean flow, ($\frac{ft^3/s}{mi^2}$)	Mean annual runoff (1,000 ac-ft)
02125000	Big Bear Creek near Richfield	56	1955-68 13 yrs	56	1.01	41
02126000	Rocky River near Norwood	1,370	1930-68 38 yrs	1280	.93	926
02127000	Brown Creek near Polkton	110	1938-68 30 yrs	87	.79	63
02128000	Little River near Star	105	1955-68 13 yrs	103	.98	75
02133500	Drowning Creek near Hoffman	178	1940-68 28 yrs	257	1.44	186
02134500	Lumber River at Boardman	1,220	1930-68 38 yrs	1290	1.06	933
02138000	Catawba River near Marion	171	1943-68 25 yrs	320	1.87	231
02138500	Linville River near Nebo	67	1923-68 45 yrs	141	2.09	102
02142000	Lower Little River near All Healing Springs	31	1954-68 14 yrs	35	1.11	25
02143000	Henry Fork near Henry River	80	1926-68 42 yrs	126	1.57	91
02143500	Indian Creek near Laboratory	68	1952-68 16 yrs	89	1.29	64
02146500	Little Sugar Creek near Charlotte	41	1925-68 43 yrs	46	1.11	33

long-term stream-gaging stations--Continued

7-day, 2-year low flow, (ft^3/s)	Percent chance of deficiency	Draft rate, in percent of mean flow: 95	90	80	70	60	50	40	30	20	10
		Storage required, expressed as a ratio to the mean annual runoff									
-	2	2.37	1.41	0.80	0.54	0.34	0.23	0.19	0.14	0.09	0.04
	5	1.83	1.08	.66	.43	.28	.23	.18	.13	.08	.03
	10	1.25	.88	.54	.36	.27	.22	.17	.12	.06	.05
67	2	2.93	1.85	1.11	.75	.50	.32	.18	.08	.04	.01
	5	1.98	1.38	.84	.58	.38	.22	.12	.07	.04	.01
	10	1.37	1.02	.67	.42	.23	.13	.10	.06	.03	.01
-	2	3.77	2.34	1.36	.93	.64	.42	.27	.15	.09	.04
	5	2.47	1.70	1.03	.72	.49	.32	.21	.13	.08	.03
	10	1.66	1.25	.83	.56	.37	.23	.18	.13	.08	.03
6	2	2.67	1.70	1.03	.70	.47	.30	.16	.08	.04	.01
	5	1.84	1.29	.78	.54	.36	.20	.12	.07	.03	.01
	10	1.29	.97	.63	.40	.23	.16	.11	.06	.03	.01
75	2	2.10	1.23	.67	.41	.20	.09	.04	.02	0	0
	5	1.56	.94	.53	.28	.12	.07	.03	.01	0	0
	10	1.11	.64	.41	.20	.09	.05	.02	.01	0	0
257	2	2.93	1.85	1.10	.74	.49	.30	.16	.05	.02	0
	5	1.97	1.37	.83	.56	.35	.18	.08	.04	0	0
	10	1.37	1.02	.66	.40	.21	.10	.06	.03	0	0
110	2	2.10	1.25	.69	.44	.24	.14	.09	.04	.01	0
	5	1.57	.95	.55	.31	.16	.11	.06	.03	0	0
	10	1.12	.75	.43	.24	.13	.08	.04	.01	0	0
29	2	1.90	1.11	.63	.39	.21	.14	.09	.04	.02	0
	5	1.41	.86	.49	.27	.17	.12	.07	.04	.02	0
	10	1.02	.70	.41	.23	.14	.09	.06	.02	0	0
10	2	3.20	2.01	1.18	.79	.54	.33	.18	.06	.02	0
	5	2.14	1.48	.90	.60	.39	.21	.09	.04	.01	0
	10	1.46	1.09	.70	.44	.24	.11	.06	.02	0	0
36	2	2.19	1.40	.86	.58	.36	.21	.07	.02	0	0
	5	1.57	1.10	.66	.43	.25	.10	.05	.02	0	0
	10	1.12	.82	.51	.29	.13	.08	.03	.01	0	0
23	2	2.43	1.55	.94	.64	.44	.27	.13	.06	.02	0
	5	1.69	1.20	.73	.49	.30	.14	.08	.04	.02	0
	10	1.20	.89	.57	.34	.17	.10	.05	.02	0	0
5.9	2	2.36	1.40	.76	.48	.26	.13	.08	.04	.02	0
	5	1.82	1.06	.62	.36	.19	.12	.07	.04	0	0
	10	1.24	.86	.48	.27	.15	.10	.06	.03	0	0

Table 1.--Draft-storage relations at

Station number	Station name	Drainage area (mi^2)	Period of record	Mean flow (ft^3/s)	Mean flow, ($\frac{ft^3/s}{mi^2}$)	Mean annual runoff (1,000 ac-ft)
02148500	Broad River near Chimney Rock	97	1928-58 30 yrs	169	1.74	122
02149000	Cove Creek near Lake Lure	77	1952-68 16 yrs	118	1.53	83
02151000	Second Broad River at Cliffside	211	1926-68 42 yrs	299	1.41	216
02151500	Broad River near Boiling Springs	864	1926-68 42 yrs	1435	1.66	1038
02152500	First Broad River near Lawndale	198	1941-68 27 yrs	279	1.40	202
03161000	South Fork New River near Jefferson	207	1925-68 43 yrs	408	1.97	295
03162500	North Fork New River at Crumpler	283	1909-58 49 yrs	472	1.67	341
03439000	French Broad River at Rosman	67.9	1908; 1936-68 34 yrs	233	3.43	169
03439500	French Broad River at Calvert	103	1925-55 30 yrs	344	3.34	249
03441000	Davidson River near Brevard	40.4	1921-68 47 yrs	127	3.14	92
03442000	Crab Creek near Penrose	10.9	1943-55 12 yrs	28.5	2.61	20
03443000	French Broad River at Blantyre	296	1921-68 47 yrs	951	3.21	688

long-term stream-gaging stations--Continued

7-day, 2-year low flow, (ft^3/s)	Percent chance of deficiency	Draft rate, in percent of mean flow									
		95	90	80	70	60	50	40	30	20	10
		Storage required, expressed as a ratio to the mean annual runoff									
39	2	2.36	1.39	0.76	0.47	0.25	0.12	0.07	0.03	0.01	0
	5	1.82	1.06	.61	.35	.18	.10	.05	.02	0	0
	10	1.23	.85	.47	.24	.11	.07	.03	.01	0	0
48	2	1.99	1.28	.79	.53	.34	.18	.07	.02	0	0
	5	1.45	1.01	.62	.39	.22	.09	.04	.01	0	0
	10	1.03	.76	.46	.25	.10	.06	.02	0	0	0
104	2	1.89	1.22	.74	.50	.30	.15	.05	.02	0	0
	5	1.39	.96	.59	.38	.20	.08	.03	.01	0	0
	10	.99	.72	.43	.21	.08	.05	.02	0	0	0
568	2	1.89	1.22	.74	.51	.31	.16	.05	.02	0	0
	5	1.39	.99	.59	.37	.18	.07	.03	.01	0	0
	10	.99	.72	.43	.21	.08	.05	.02	0	0	0
97	2	2.36	1.39	.75	.46	.25	.11	.06	.02	0	0
	5	1.82	1.06	.61	.34	.17	.09	.04	.01	0	0
	10	1.23	.84	.45	.23	.09	.06	.03	.01	0	0
152	2	1.69	.97	.53	.30	.12	.08	.04	.01	0	0
	5	1.24	.75	.40	.19	.09	.06	.03	0	0	0
	10	.89	.58	.28	.08	.06	.05	.02	0	0	0
128	2	1.70	.99	.56	.33	.17	.12	.07	.03	0	0
	5	1.25	.77	.43	.23	.15	.10	.05	.02	0	0
	10	.91	.61	.34	.16	.12	.08	.04	.01	0	0
110	2	1.53	.90	.49	.28	.14	.09	.05	.02	0	0
	5	1.11	.68	.36	.16	.11	.07	.03	.01	0	0
	10	.82	.55	.29	.12	.08	.05	.02	0	0	0
115	2	1.70	.99	.56	.33	.16	.11	.06	.02	0	0
	5	1.24	.76	.42	.21	.12	.08	.04	.01	0	0
	10	.90	.60	.32	.13	.09	.06	.03	.01	0	0
39	2	1.70	.99	.56	.33	.16	.11	.06	.03	0	0
	5	1.24	.76	.42	.21	.13	.09	.05	.02	0	0
	10	.91	.60	.33	.14	.10	.07	.04	.01	0	0
10	2	1.89	1.11	.62	.37	.18	.09	.05	.02	0	0
	5	1.40	.84	.46	.22	.10	.07	.04	.01	0	0
	10	1.01	.69	.38	.18	.09	.06	.02	0	0	0
316	2	1.70	.98	.55	.32	.15	.10	.05	.02	0	0
	5	1.25	.76	.41	.19	.10	.07	.04	.01	0	0
	10	.90	.59	.31	.12	.09	.06	.03	0	0	0

Table 1.--Draft-storage relations at

Station number	Station name	Drainage area (mi^2)	Period of record	Mean flow (ft^3/s)	Mean flow, ($\frac{ft^3/s}{mi^2}$)	Mean annual runoff (1,000 ac-ft)
03444000	Boylston Creek near Horseshow	14.8	1943-55 12 yrs	32.8	2.22	24
03444500	South Fork Mills River at The Pink Beds	9.99	1927-68 41 yrs	31.2	3.13	23
03446000	Mills River at Mills River	66.7	1925, 1926; 1934-68 37 yrs	161	2.42	117
03447000	Mud Creek at Naples	109	1939-55 16 yrs	196	1.80	142
03447500	Cane Creek at Fletcher	63.1	1943-58 15 yrs	74	1.17	54
03448000	French Broad River at Bent Creek	676	1935-68 33 yrs	1640	2.43	1186
03448500	Hominy Creek at Candler	79.8	1943-68 25 yrs	91.2	1.14	66
03449000	North Fork Swannanoa River near Black Mountain	23.8	1927-57 30 yrs	47.5	2.00	35
03450000	Beetree Creek near Swannanoa	5.46	1927-68 41 yrs	10.5	1.92	760
03451000	Swannanoa River at Biltmore	130	1921-68 47 yrs	158	1.21	114
03451500	French Broad River at Asheville	945	1896-1955 59 yrs	2071	2.19	1497
03452000	Sandymush Creek near Alexander	79.5	1945-55 10 yrs	57.6	.72	42

long-term stream-gaging stations--Continued

7-day, 2-year low flow, (ft^3/s)	Percent chance of deficiency	Draft rate, in percent of mean flow									
		95	90	80	70	60	50	40	30	20	10
		Storage required, expressed as a ratio to the mean annual runoff									
12	2	2.10	1.24	.68	.42	.21	.10	.05	.02	0	0
	5	1.56	.93	.52	.26	.10	.07	.04	.01	0	0
	10	1.11	.74	.41	.20	.08	.05	.02	0	0	0
6.6	2	1.70	.99	.57	.34	.18	.13	.08	.04	.02	0
	5	1.25	.77	.44	.24	.16	.11	.06	.03	.01	0
	10	.90	.60	.32	.14	.11	.08	.05	.02	0	0
50	2	1.90	1.12	.63	.39	.20	.13	.08	.04	.01	0
	5	1.41	.85	.48	.25	.14	.10	.06	.02	0	0
	10	1.01	.69	.39	.19	.10	.07	.04	.01	0	0
68	2	1.70	.98	.55	.32	.15	.10	.05	.02	0	0
	5	1.25	.76	.42	.21	.12	.08	.04	.02	0	0
	10	.90	.59	.31	.12	.09	.06	.03	.01	0	0
22	2	2.36	1.40	.76	.47	.25	.12	.07	.03	0	0
	5	1.82	1.06	.61	.35	.19	.11	.06	.02	0	0
	10	1.24	.86	.48	.26	.14	.09	.04	.01	0	0
576	2	1.70	.98	.54	.31	.13	.09	.05	.02	0	0
	5	1.24	.75	.41	.20	.11	.07	.04	.01	0	0
	10	.90	.59	.31	.12	.08	.05	.02	0	0	0
31	2	1.99	1.28	.79	.53	.33	.18	.06	.02	0	0
	5	1.45	1.01	.61	.39	.22	.09	.04	.01	0	0
	10	1.03	.75	.45	.24	.09	.06	.03	0	0	0
3.3	2	2.37	1.41	.79	.53	.33	.22	.17	.12	.07	.02
	5	1.83	1.08	.65	.41	.26	.20	.15	.10	.05	.01
	10	1.25	.88	.53	.33	.23	.18	.13	.08	.04	.01
1.4	2	1.71	1.01	.60	.38	.23	.18	.13	.08	.03	.01
	5	1.25	.78	.46	.27	.21	.16	.11	.06	.03	0
	10	.92	.64	.39	.24	.19	.14	.09	.05	.01	0
32	2	2.10	1.25	.70	.45	.25	.16	.11	.06	.02	0
	5	1.57	.95	.56	.33	.19	.14	.09	.04	.01	0
	10	1.12	.76	.45	.26	.16	.11	.06	.03	.01	0
724	2	2.10	1.23	.67	.40	.19	.08	.05	.02	0	0
	5	1.56	.93	.52	.26	.10	.07	.04	.01	0	0
	10	1.11	.74	.41	.20	.08	.05	.02	0	0	0
16	2	2.36	1.40	.76	.48	.27	.14	.09	.04	.01	0
	5	1.82	1.06	.62	.37	.20	.13	.08	.03	0	0
	10	1.24	.86	.48	.27	.15	.10	.05	.02	0	0

Table 1.--Draft-storage relations at

Station number	Station name	Drainage area (mi^2)	Period of record	Mean flow (ft^3/s)	Mean flow, ($\frac{ft^3/s}{mi^2}$)	Mean annual runoff (1,000 ac-ft)
03453000	Ivy River near Marshall	158	1935-68 33 yrs	154	0.97	111
03453500	French Broad River at Marshall	1,332	1943-68 25 yrs	2370	1.78	1668
03454000	Big Laurel Creek near Stackhouse	126	1935-68 33 yrs	187	1.48	135
03454500	French Broad River at Hot Springs	1,565	1916; 1935-49 15 yrs	2612	1.67	1889
03455500	West Fork Pigeon River above Lake Logan near Hazelwood	27.6	1955-68 13 yrs	99.9	3.61	72
03456500	East Fork Pigeon River near Canton	51.5	1955-68 13 yrs	135	2.62	98
03457000	Pigeon River at Canton	133	1907-09 1928-68 42 yrs	313	2.35	226
03459000	Jonathan Creek near Cove Creek	65.3	1931-68 37 yrs	129	1.97	93
03459500	Pigeon River near Hepco	350	1928-68 40 yrs	660	1.88	477
03460000	Cataloochee Creek near Cataloochee	49.2	1935-68 33 yrs	108	2.19	78
03462000	North Toe River at Altapass	104	1939-57 18 yrs	187	1.80	135
03463300	South Toe River near Celo	43.4	1958-68 10 yrs	136	3.13	98

long-term stream-gaging stations--Continued

7-day, 2-year low flow, (ft^3/s)	Percent chance of deficiency	Draft rate, in percent of mean flow									
		95	90	80	70	60	50	40	30	20	10
		Storage required, expressed as a ratio to the mean annual runoff									
29	2	1.90	1.12	.64	.40	.22	.15	.10	.05	.02	0
	5	1.41	.86	.50	.28	.18	.13	.08	.04	.01	0
	10	1.02	.71	.42	.24	.16	.11	.06	.03	0	0
309	2	1.70	.99	.55	.32	.15	.10	.05	.02	0	0
	5	1.25	.76	.42	.21	.12	.08	.04	.01	0	0
	10	.90	.59	.31	.12	.09	.06	.03	.01	0	0
41	2	1.52	.98	.61	.41	.25	.15	.10	.05	.01	0
	5	1.13	.76	.47	.29	.18	.13	.08	.04	0	0
	10	.87	.62	.37	.21	.16	.11	.06	.03	0	0
870	2	1.90	1.11	.61	.36	.17	.08	.04	.02	0	0
	5	1.40	.84	.45	.22	.09	.06	.03	.01	0	0
	10	1.01	.69	.38	.18	.08	.05	.02	0	0	0
20	2	1.19	.68	.41	.25	.19	.14	.09	.04	.01	0
	5	.88	.58	.33	.24	.18	.12	.06	.03	.01	0
	10	.69	.49	.26	.17	.13	.09	.05	.02	0	0
28	2	1.26	.82	.53	.35	.21	.16	.11	.06	.02	0
	5	.95	.67	.41	.24	.19	.14	.09	.04	.01	0
	10	.75	.54	.32	.21	.16	.11	.06	.03	.01	0
-	2	1.53	.91	.50	.30	.17	.12	.07	.04	.01	0
	5	1.12	.70	.39	.21	.16	.11	.06	.03	.01	0
	10	.83	.56	.31	.14	.11	.08	.05	.02	0	0
37	2	1.34	.86	.53	.32	.16	.09	.05	.02	0	0
	5	1.00	.68	.40	.21	.12	.08	.04	.01	0	0
	10	.77	.54	.29	.13	.09	.06	.03	.01	0	0
174	2	1.70	.99	.56	.33	.16	.11	.06	.02	0	0
	5	1.25	.76	.43	.22	.13	.09	.05	.02	0	0
	10	.90	.60	.30	.14	.10	.07	.04	.01	0	0
30	2	1.43	.91	.56	.36	.20	.11	.06	.02	0	0
	5	1.07	.72	.43	.25	.15	.10	.05	.02	0	0
	10	.82	.57	.32	.16	.12	.08	.04	.01	0	0
52	2	1.53	.90	.49	.27	.13	.09	.05	.02	0	0
	5	1.11	.68	.36	.16	.12	.08	.05	.02	0	0
	10	.83	.56	.30	.13	.10	.07	.04	.01	0	0
35	2	.95	.46	.32	.25	.20	.15	.10	.06	.02	0
	5	.67	.46	.27	.21	.16	.12	.07	.03	0	0
	10	.55	.40	.17	.14	.11	.08	.05	.02	0	0

Table 1.--Draft-storage relations at

Station number	Station name	Drainage area (mi^2)	Period of record	Mean flow (ft^3/s)	Mean flow, ($\frac{ft^3/s}{mi^2}$)	Mean annual runoff (1,000 ac-ft)
03463500	South Toe River at Newdale	60.8	1935-52 17 yrs	176	2.89	127
03464000	Cane River near Sioux	157	1935-68 33 yrs	250	4.39	181
03464500	Nolichucky River at Poplar	608	1926-55 29 yrs	1015	1.67	734
03479000	Watauga River near Sugar Grove	90.8	1941-68 27 yrs	161	1.77	116
03479500	Watauga River at N.C.-Tennessee State Line	152	1944-54 11 yrs	256	1.68	185
03481000	Elk River near Elk Park	42	1935-55 20 yrs	81.5	1.94	59
03500000	Little Tennessee River near Prentiss	140	1945-68 23 yrs	381	2.72	139
03501000	Cullasaja River at Cullasaja	86.5	1908-09 1922-68 48 yrs	224	2.57	162
03502000	Little Tennessee River at Iotla	323	1930-45 15 yrs	736	2.27	532
03503000	Little Tennessee River at Needmore	436	1945-68 23 yrs	1045	2.39	756
03504000	Nantahala River near Rainbow Springs	51.9	1941-68 27 yrs	197	3.78	143
03506500	Nantahala River at Almond	174	1913-43 30 yrs	509	2.92	368

long-term stream-gaging stations--Continued

7-day, 2-year low flow, (ft^3/s)	Percent chance of deficiency	Draft rate, in percent of mean flow									
		95	90	80	70	60	50	40	30	20	10
		Storage required, expressed as a ratio to the mean annual runoff									
40	2	1.91	1.12	.63	.38	.20	.12	.08	.04	.01	0
	5	1.41	.86	.48	.26	.14	.10	.07	.03	0	0
	10	1.01	.70	.40	.20	.11	.08	.04	.02	0	0
63	2	1.43	.91	.57	.36	.20	.12	.07	.03	0	0
	5	1.07	.72	.43	.25	.14	.10	.06	.02	0	0
	10	.82	.57	.32	.15	.12	.08	.05	.01	0	0
278	2	1.70	.99	.56	.32	.15	.11	.06	.03	0	0
	5	1.25	.76	.42	.21	.12	.09	.06	.02	0	0
	10	.91	.60	.32	.13	.10	.07	.04	.01	0	0
32	2	1.70	1.00	.58	.36	.20	.15	.10	.06	.02	0
	5	1.25	.78	.45	.26	.19	.14	.09	.05	.01	0
	10	.91	.62	.36	.20	.15	.11	.07	.04	0	0
43	2	1.70	1.00	.59	.37	.22	.17	.12	.07	.04	0
	5	1.26	.78	.47	.28	.21	.16	.11	.06	.01	0
	10	.92	.64	.39	.24	.19	.14	.09	.05	0	0
17	2	1.25	.82	.52	.34	.20	.15	.10	.06	.03	0
	5	.95	.67	.41	.24	.19	.14	.09	.05	.02	0
	10	.75	.54	.33	.22	.17	.12	.07	.04	.01	0
114	2	1.53	.90	.47	.25	.11	.08	.05	.01	0	0
	5	1.11	.68	.36	.16	.12	.08	.04	.01	0	0
	10	.82	.55	.29	.12	.09	.06	.03	.01	0	0
59	2	1.70	.99	.56	.34	.17	.12	.07	.04	.01	0
	5	1.25	.77	.44	.24	.16	.11	.06	.03	0	0
	10	.90	.60	.32	.14	.11	.08	.05	.02	0	0
236	2	1.52	.96	.58	.37	.20	.09	.05	.02	0	0
	5	1.12	.74	.43	.24	.11	.07	.03	.01	0	0
	10	.85	.58	.30	.11	.08	.05	.02	0.	0	0
307	2	1.35	.78	.43	.23	.12	.08	.04	.01	0	0
	5	.98	.61	.30	.13	.10	.07	.04	.01	0	0
	10	.75	.51	.26	.12	.09	.06	.03	0	0	0
57	2	1.20	.66	.38	.20	.12	.08	.04	.01	0	0
	5	.87	.56	.27	.15	.11	.07	.03	.01	0	0
	10	.68	.47	.23	.12	.09	.06	.03	.01	0	0
143	2	1.88	1.22	.71	.48	.30	.14	.05	.03	0	0
	5	1.38	.91	.55	.35	.18	.09	.05	.02	0	0
	10	1.02	.70	.42	.21	.11	.07	.03	.01	0	0

Table 1.--Draft-storage relations at

Station number	Station name	Drainage area (mi^2)	Period of record	Mean flow (ft^3/s)	Mean flow, ($\frac{ft^3/s}{mi^2}$)	Mean annual runoff (1,000 ac-ft)
03509000	Scott Creek above Sylva	50.7	1942-68 26 yrs	112	2.19	81
03509500	Scott Creek at Sylva	50	1929-41 12 yrs	105	2.10	76
03511000	Oconaluftee River at Cherokee	131	1922-49 27 yrs	382	2.91	276
03512000	Oconaluftee River at Birdtown	184	1946-68 22 yrs	509	2.76	368
03513000	Tuckasegee River at Bryson City	655	1898-1940 43 yrs	1605	2.45	1161
03513500	Noland Creek near Bryson City	13.8	1936-68 32 yrs	45	3.21	32
03517000	Cheoah River at Johnson	177	1913-26 13 yrs	510	2.88	369
03546000	Shooting Creek near Hayesville	37.6	1923-55 32 yrs	88	2.35	64
03550000	Valley River at Tomotla	104	1905-09, 1915-16, 1920-68 56 yrs	254	2.44	183
03554000	Nottely River near Ranger	272	1902-45 44 yrs	501	1.84	362

long-term stream-gaging stations--Continued

7-day, 2-year low flow, (ft^3/s)	Percent chance of deficiency	Draft rate, in percent of mean flow: 95	90	80	70	60	50	40	30	20	10
		Storage required, expressed as a ratio to the mean annual runoff									
37	2	1.53	.90	.48	.26	.12	.08	.03	.01	0	0
	5	1.11	.67	.35	.14	.10	.07	.03	0	0	0
	10	.82	.55	.28	.10	.08	.05	.02	0	0	0
36	2	2.36	1.39	.75	.46	.23	.09	.04	.02	0	0
	5	1.82	1.05	.60	.33	.15	.07	.04	.01	0	0
	10	1.23	.84	.46	.23	.10	.06	.02	0	0	0
103	2	1.43	.91	.55	.34	.18	.08	.05	.02	0	0
	5	1.06	.70	.41	.21	.10	.07	.04	.02	0	0
	10	.81	.55	.28	.10	.09	.06	.03	.01	0	0
135	2	1.19	.66	.39	.21	.13	.09	.05	.03	0	0
	5	.87	.56	.27	.15	.11	.08	.05	.02	0	0
	10	.68	.48	.25	.14	.10	.07	.04	.01	0	0
549	2	1.61	1.02	.61	.39	.21	.08	.05	.02	0	0
	5	1.18	.77	.45	.25	.10	.07	.04	.01	0	0
	10	.89	.61	.33	.13	.09	.06	.03	.01	0	0
10	2	1.19	.68	.41	.25	.19	.14	.09	.04	.01	0
	5	.88	.58	.32	.22	.17	.12	.07	.03	.01	0
	10	.69	.50	.27	.18	.13	.09	.05	.02	0	0
131	2	1.90	1.11	.62	.38	.19	.11	.07	.04	.02	0
	5	1.41	.85	.47	.24	.12	.09	.06	.03	.01	0
	10	1.01	.70	.39	.20	.11	.08	.05	.02	0	0
21	2	1.90	1.12	.64	.40	.21	.14	.09	.04	.01	0
	5	1.41	.86	.50	.23	.18	.13	.08	.03	0	0
	10	1.02	.71	.42	.24	.16	.11	.06	.02	0	0
50	2	1.80	1.16	.70	.48	.32	.17	.10	.05	.02	0
	5	1.31	.88	.54	.36	.19	.13	.08	.04	.01	0
	10	.99	.69	.43	.22	.17	.12	.07	.03	0	0
150	2	3.35	1.82	1.00	.72	.50	.33	.18	.04	.02	0
	5	1.86	1.24	.77	.52	.32	.16	.06	.03	0	0
	10	1.32	.93	.59	.36	.19	.09	.05	.02	0	0

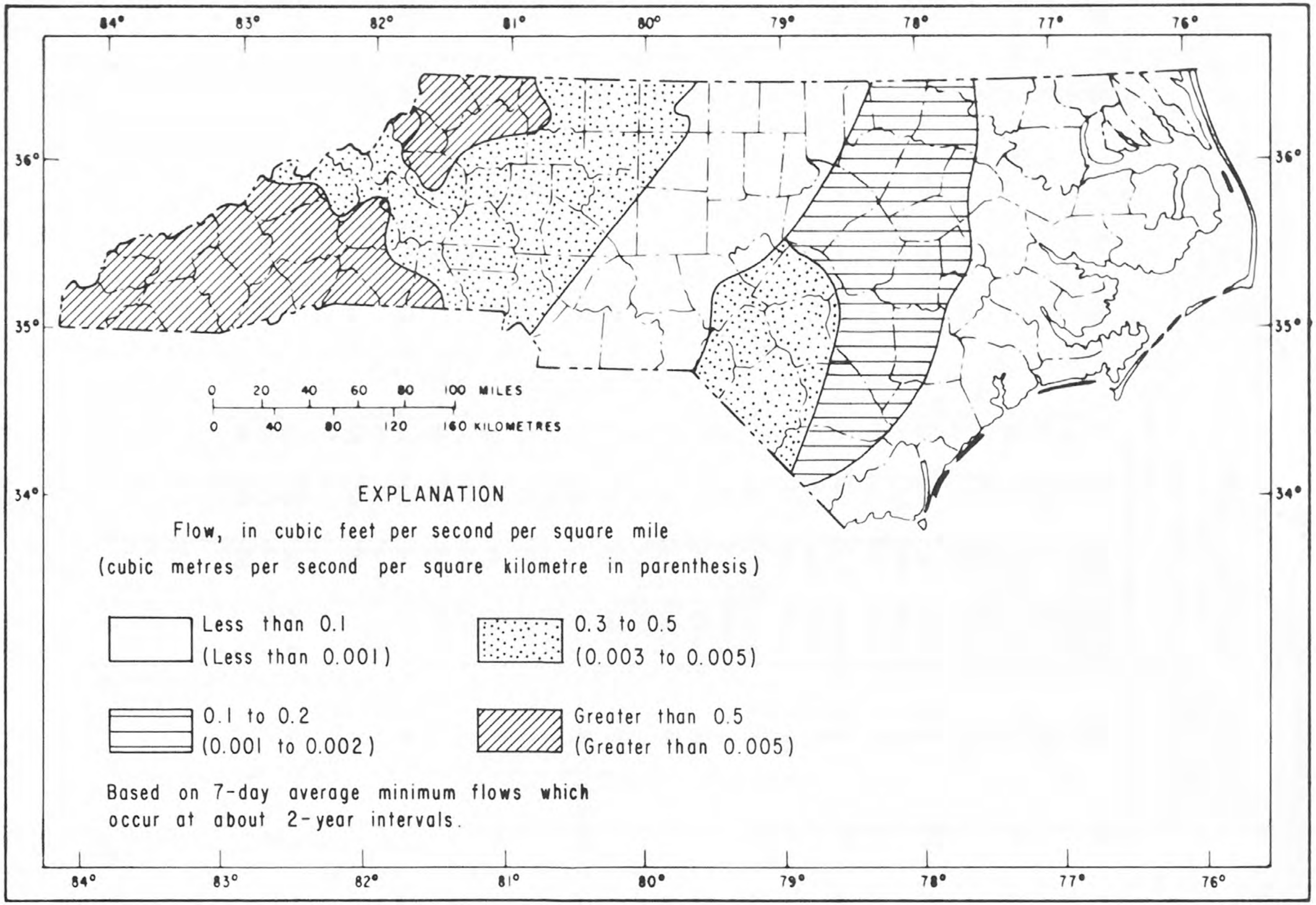

Figure 3.--Range in low flow of streams in North Carolina.

during 1931-70, ranged from 68 inches (1,730 mm) in the southwestern part of the State to 42 inches (1,070 mm) in the northern part of the Piedmont (Saucier and others, 1973, p. 72). Annual net evaporation, which is the excess of yearly evaporation over yearly rainfall, is consistently negative in the mountainous western part of the State but may be either positive or negative in the Piedmont and Coastal Plain. Net evaporation is larger in the Piedmont than in the Coastal Plain, because of the generally higher rainfall near the coast. However, a reservoir impounding a given volume of water in the Coastal Plain will have approximately twice the surface area of one in the Piedmont and four times that of one in the mountains. In spite of having less surface area from which evaporation can occur, annual net evaporation losses from Piedmont reservoirs usually exceed those from reservoirs in the Coastal Plain (because of higher precipitation near the coast). Since annual net evaporation is negative in western North Carolina, there is no annual net evaporation loss from reservoirs in that part of the State.

Sedimentation

It is often necessary to provide extra storage in reservoirs to accommodate the sediment that runs off upstream areas. Depending on the land practices in the drainage basin upstream from the reservoir, this extra storage may be significant. The sediment yield from a highly exposed basin, as during periods of major construction, may be several orders of magnitude greater than the yield from an undisturbed, wooded basin.

Seepage

Only in rare instances is seepage a significant loss in reservoirs. It can be disastrous however, in certain regions of the country. There are a number of instances where seepage losses are so great that the reservoirs often go dry or never fill. In North Carolina, the most serious losses due to seepage could occur as underflow beneath the dam. Such a condition would occur if the dam was not extended to bedrock. In the mountains and Piedmont, bedrock is found at relatively shallow depths; thus seepage may occur in relatively minor amounts. In the Coastal Plain, bedrock is found at considerable depth and as a result, reservoirs may be more susceptible to seepage losses.

DERIVATION OF DRAFT-STORAGE RELATIONS

The analysis to develop a set of draft-storage relations, enabling the user to determine the water-supply potential of any site on any stream in the State, required two steps. Individual draft-storage relations were first developed for selected sites on many streams to provide an adequate data base. Then, the data were regionalized based on geographic patterns and the spatial distribution of a statistical variability index of the mean annual flow of streams.

Individual draft-storage relations for 2, 5, and 10 percent chance of deficiency--that is, for recurrence intervals of 50, 20, and 10 years, respectively--are available at 142 sites (plate 1). These relations appear in table 1 and may be used directly for the design of reservoirs at these sites. These draft-storage relations were computed using the annual mass-curve method and the probability-routing method, a combination recommended and described by Riggs and Hardison (1973). The annual-mass-curve method defines the relation for lower draft rates, which are dependent on the seasonal variation of streamflow. Results of the probability-routing method (after adjustment for seasonal variations) define that part of the draft-storage relation which depends on over-year storage.

After obtaining draft-storage data for sites throughout the State, it became apparent that the relations were very similar for sites within broad geographic areas. This similarity allowed us to divide the State into zones A, B, C, and D and use a typical, or average, draft-storage relation for all the streams in each zone. Zones A and B were further subdivided into subzones A_1, A_2, B_1, and B_2 on the basis of the areal distribution of these relations. The zones appear on plate 1.

The draft-storage relations for 2, 5, and 10 percent probabilities of deficiencies for each zone are shown on figures 4-7. These relations may be used to estimate the storage necessary to furnish a required draft at any site on any stream in the applicable zone. A reservoir sized according to one of these curves would be expected to furnish the required draft every year except one, on the average, during periods of 10, 20, or 50 years, depending on the probability of deficiency.

To use these relations, one must determine the drainage area of the stream above the reservoir site, the mean annual flow of the stream, and the zone in which the site is located. The drainage area can be determined by standard engineering methods--usually with a polar planimeter or a grid system. The mean annual flow can be estimated from plate 1. This plate is based on data collected at more than 150 gaging stations in North Carolina and adjoining States (Yonts, 1971). The runoff values represent natural flow conditions--essentially unaffected by man. Because mean annual flow in the mountains is greatly dependent on altitude, the lines of equal flow shown for areas of the State above the 1,000-foot (305 m) contour are also based on altitude, as well as on the data collected at gaging stations.

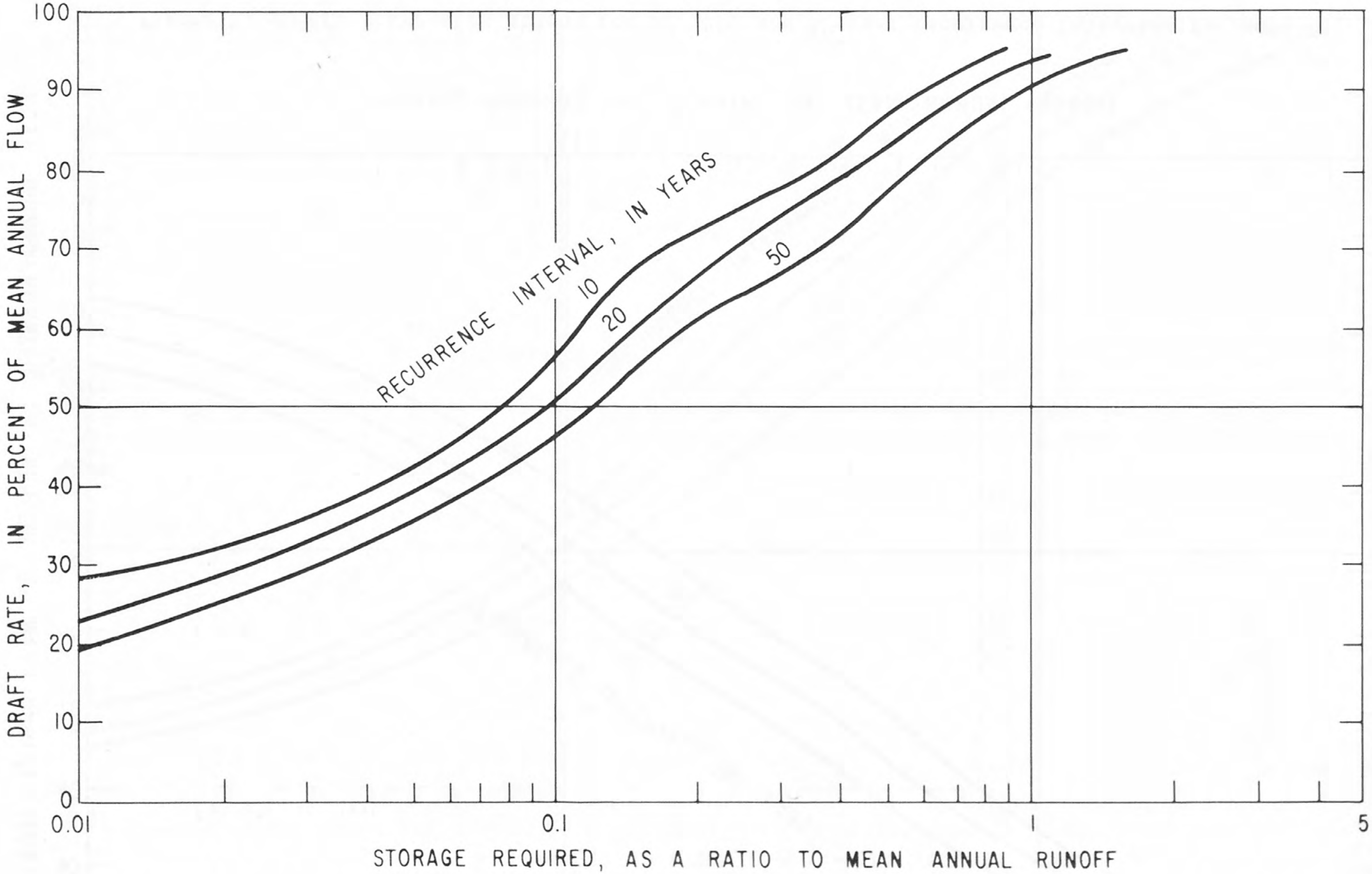

Figure 4.--Draft-storage relations for 10, 20, and 50-year recurrence intervals for zone A.

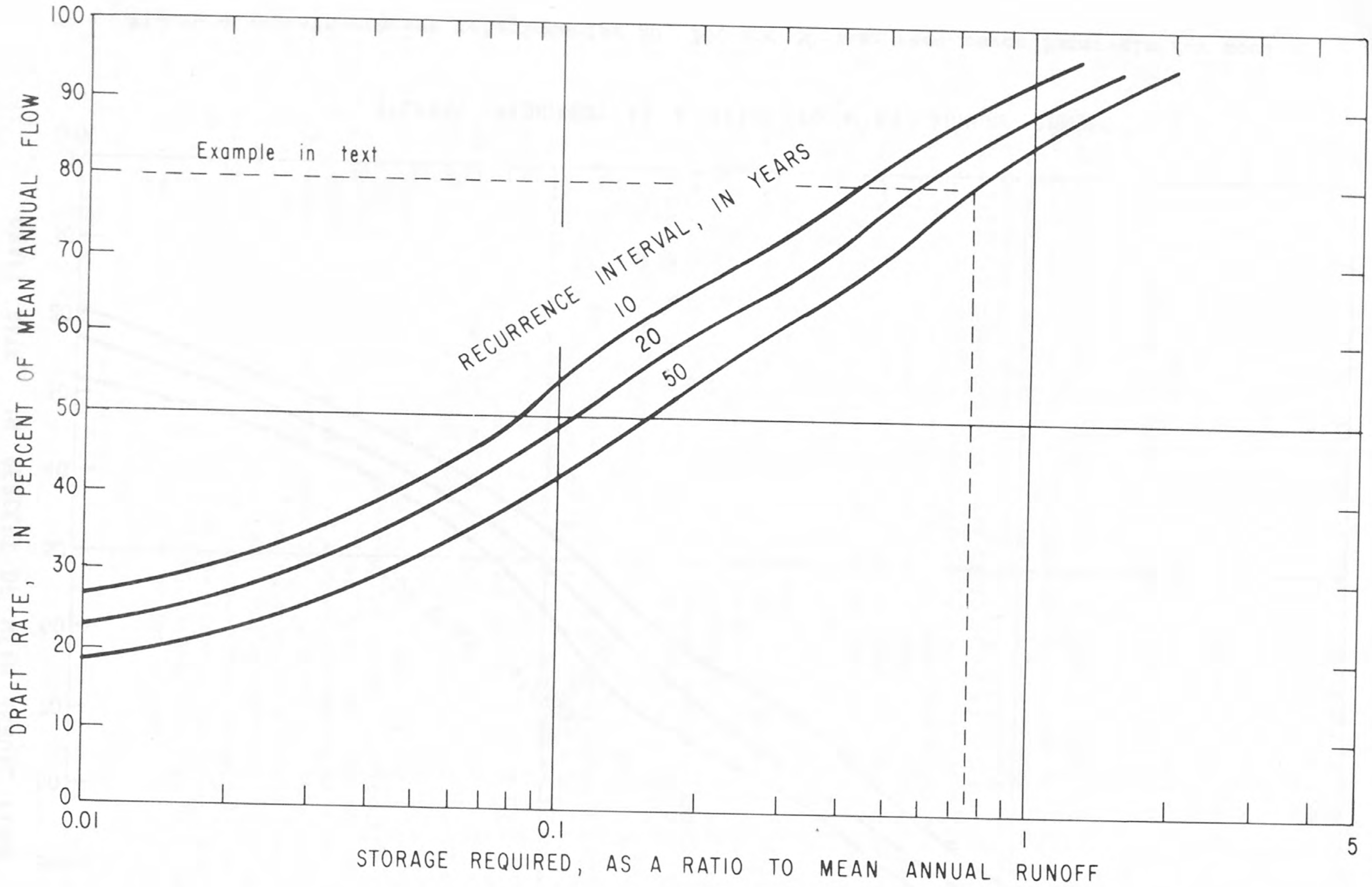

Figure 5.--Draft-storage relations for 10, 20, and 50-year recurrence intervals for zone B.

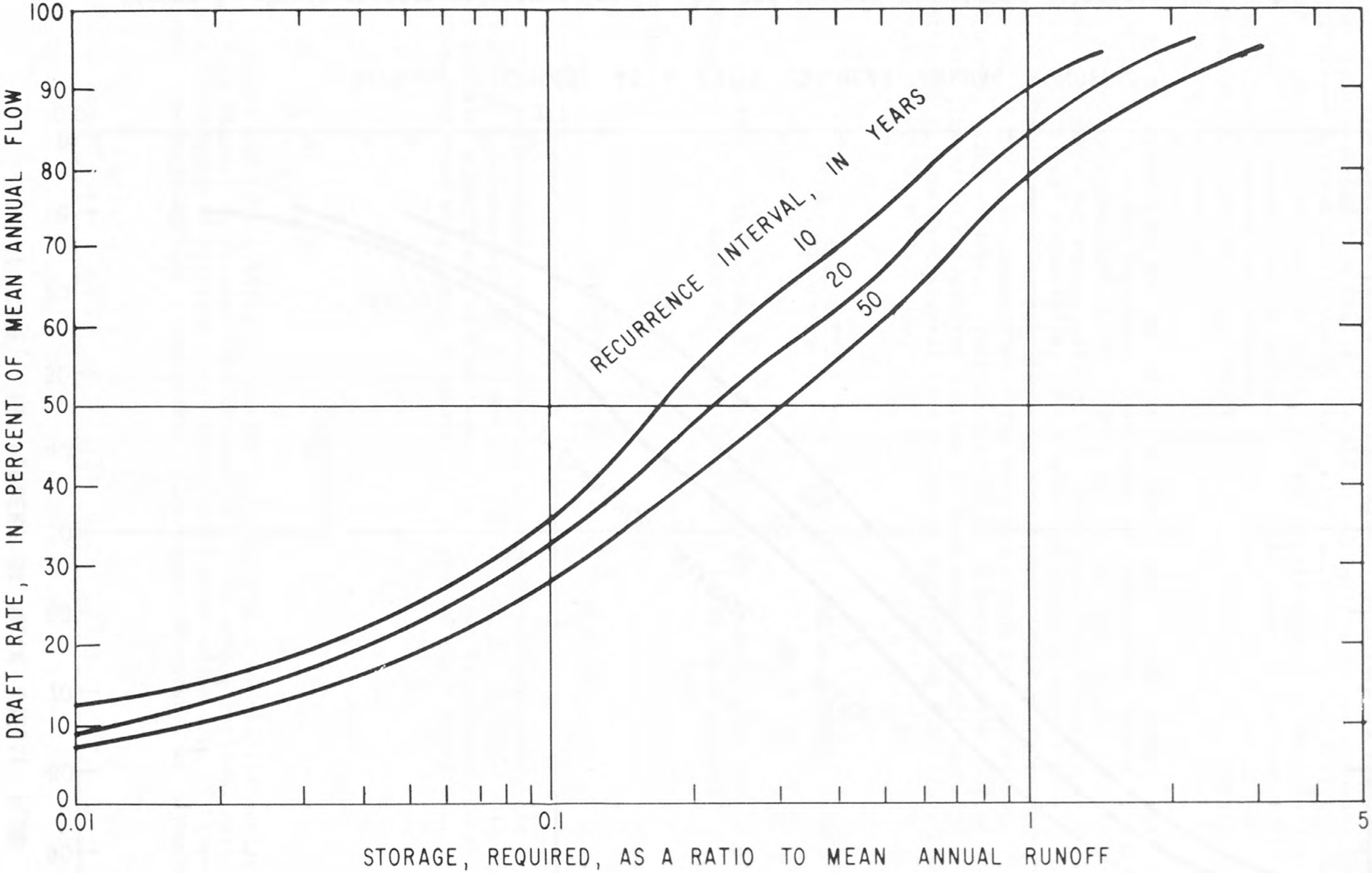

Figure 6.--Draft-storage relations for 10, 20, and 50-year recurrence intervals for zone C.

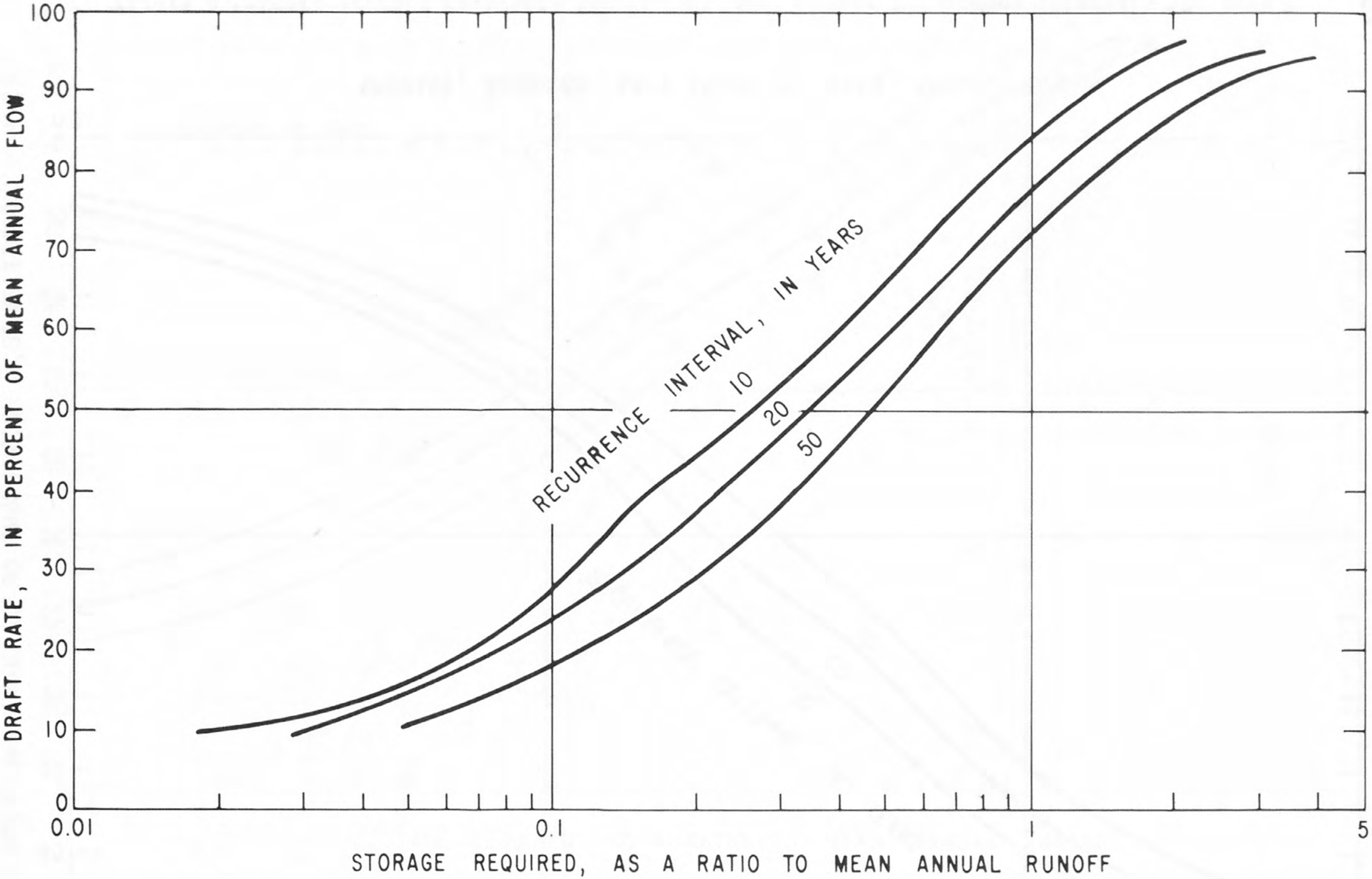

Figure 7.--Draft-storage relations for 10, 20, and 50-year recurrence intervals for zone D.

An investigator should sketch the drainage boundaries on the map for the basin upstream from the site to aid in estimating the mean annual flow. The stream pattern on the map may be used to approximate the drainage boundary. Then, if the lines of equal flow are evenly spaced across the drainage basin, mean annual flow can be estimated as the value in the center of this basin, interpolating if necessary. If the lines of equal flow are unevenly spaced and many of them cross the basin, care must be taken to obtain a mean value for the area.

As an example of the use of the draft-storage curves, assume that a hypothetical site on Hunting Creek, just north of Statesville, has a drainage area of 100 square miles (259 km^2). From plate 1, the mean annual flow in cubic feet per second per square mile is 1.0. The mean annual flow would be 100 mi^2 x 1.0 $(ft^3/s)/mi^2$ = 100 ft^3/s, or 2.8 m^3/s. Suppose an annual average draft of 80 ft^3/s (2.2 m^3s) is required from the stream. This draft represents 80 percent of the mean annual flow. The site is in zone B_1; therefore, from figure 5, using a 50-year recurrence interval (2 percent chance of deficiency), the ratio of required storage to mean annual runoff is 0.75. This ratio can be quickly converted to a volume by multiplying 0.75 times the mean annual flow, 100 ft^3/s. Now,

$$75 \text{ ft}^3/\text{s} \times \frac{1.98 \text{ acre-ft}}{\text{ft}^3/\text{s-day}} \times 365 \text{ days} = 54{,}200 \text{ acre-ft or } 67 \text{ hm}^3$$

One acre-foot is the volume of water required to cover an acre to a depth of 1 foot and is equivalent to 325,851 gallons or 1,233 cubic metres.

ADJUSTMENTS TO DRAFT-STORAGE RELATIONS

The draft-storage curves appearing on figures 4-7 are unadjusted for the effects of lake evaporation, sedimentation, or seepage. Because these losses may be quite significant in some cases, the following paragraphs contain information that will permit estimates to be made of their magnitude.

Evaporation

Yonts and others (1973) published a table of mean annual lake evaporation for Lake Michie, N. C., for 1962 through 1971. To make a regional analysis, it was necessary to transfer these annual lake evaporation data to other locations. Recognizing that evaporation varies across the State, we adjusted these annual values to be representative of selected locations in the Coastal Plain, Piedmont, and mountains by multiplying the annual evaporation data observed at Lake Michie by the ratio of the long-term pan evaporation at the selected location to that at Lake Michie as defined by Kohler and others (1959).

To obtain net evaporation at the selected sites, we subtracted the annual precipitation for each of the years from 1962 through 1971 from the corresponding adjusted annual lake evaporation. Then, using the general method outlined by Riggs (1968), we graphically fitted the net evaporation data to an arithmetic normally-distributed frequency curve. As in the case of the draft-storage relation, we found the frequency curves tended to be similar in broad geographic regions. These regions corresponded rather closely with the physiographic provinces; so, for purposes of determining evaporation losses from reservoirs, the State was divided into the Coastal Plain, Piedmont, and mountains.

The probability of evaporation exceeding precipitation is very slight in the mountains. Net evaporation is negative on all frequency curves derived for the mountains even when extended to the 50-year recurrence interval; thus, no correction for net evaporative losses is necessary. Net evaporation is highest in the Piedmont, primarily reflecting the generally lower precipitation of that region. In the Coastal Plain, net evaporation was somewhat lower than in the Piedmont, but is a significant loss, nevertheless. The maximum net lake evaporation frequency curves for the Coastal Plain and Piedmont appear on figure 8.

The next step in the analysis of evaporation losses was to develop relations between the capacity and surface area of reservoirs in the Coastal Plain and Piedmont. An inventory of dams in the State (North Carolina Department of Water and Air Resources, 1969), provided the basic data, and the resulting relations are shown in figure 9.

The influence of topography on reservoir design is apparent from the figure. Given the same storage capacity, reservoirs in the Coastal Plain tend to have more than twice the surface area of reservoirs in the Piedmont. Therefore, reservoirs in the deeper Piedmont valleys appear to be less affected by evaporation than reservoirs of the same capacity in the Coastal Plain.

To use the evaporation data to adjust the draft-storage curves, which are in terms of reservoir capacity, or storage, it was necessary to combine the maximum annual net evaporation versus recurrence interval in figure 8 with the relation between lake area and capacity in figure 9 for each of the two physiographic provinces. They were combined by plotting values of lake volume versus the product of the evaporation for a selected recurrence interval and two-thirds of the lake surface area corresponding to those volumes. This product, divided by 724, is the estimated evaporative draft in cubic feet per second from a reservoir for the indicated frequency of occurrence. As Hudson and Roberts (1955) suggest, two-thirds of the total area is an approximation of the average surface area of a lake as it empties during the critical design-period drought. The resulting curves, in terms of evaporative draft versus reservoir storage are shown in figures 10 and 11.

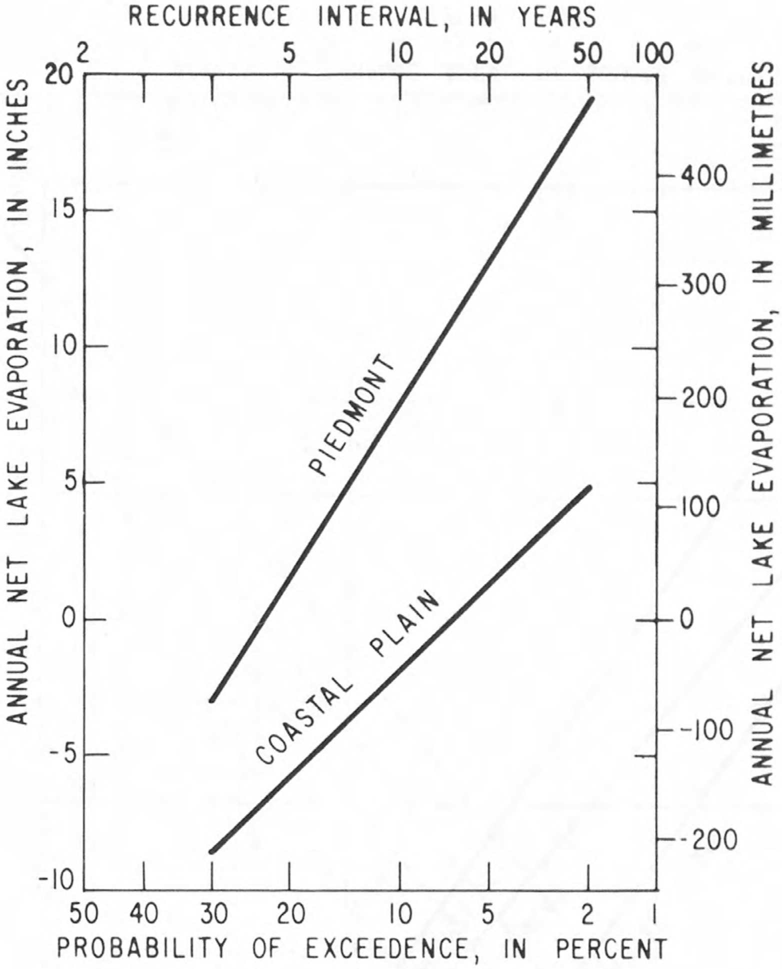

Figure 8.--Frequency and magnitude of annual net lake evaporation for the Coastal Plain and Piedmont.

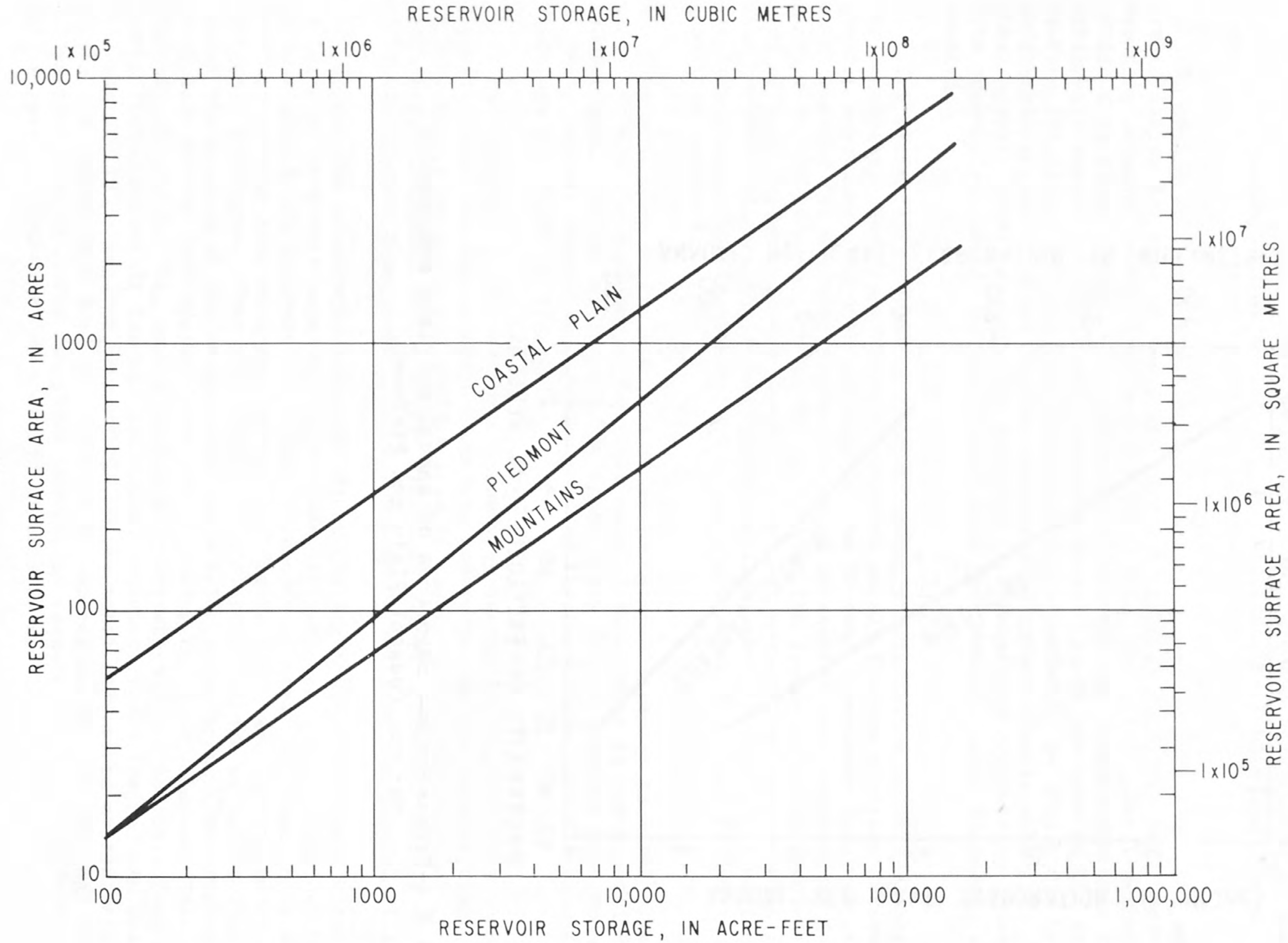

Figure 9.--Relation between lake-surface area and reservoir storage in the Piedmont, Coastal Plain, and mountains.

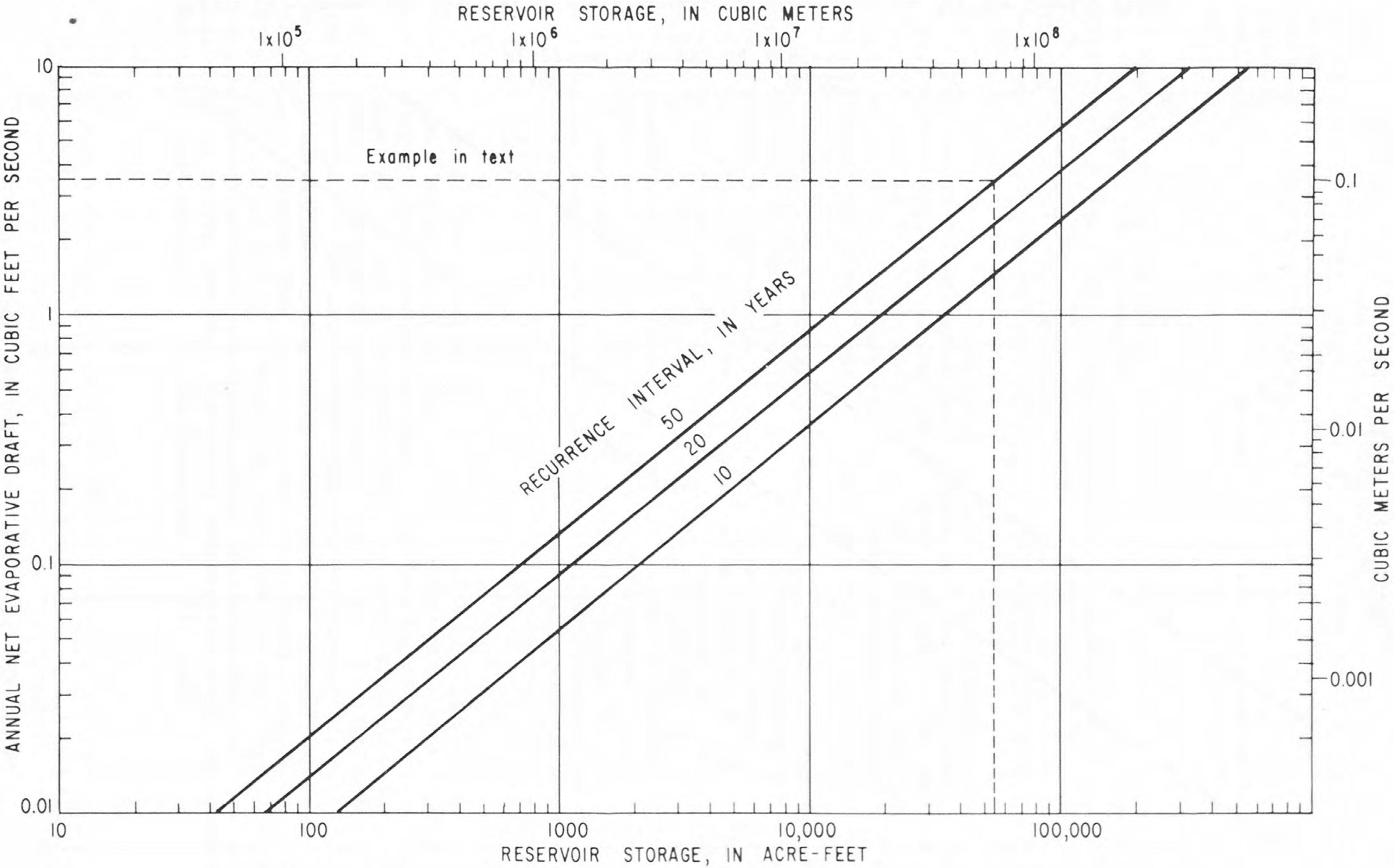

Figure 10.--Annual net evaporative draft-storage-frequency relation for the Piedmont.

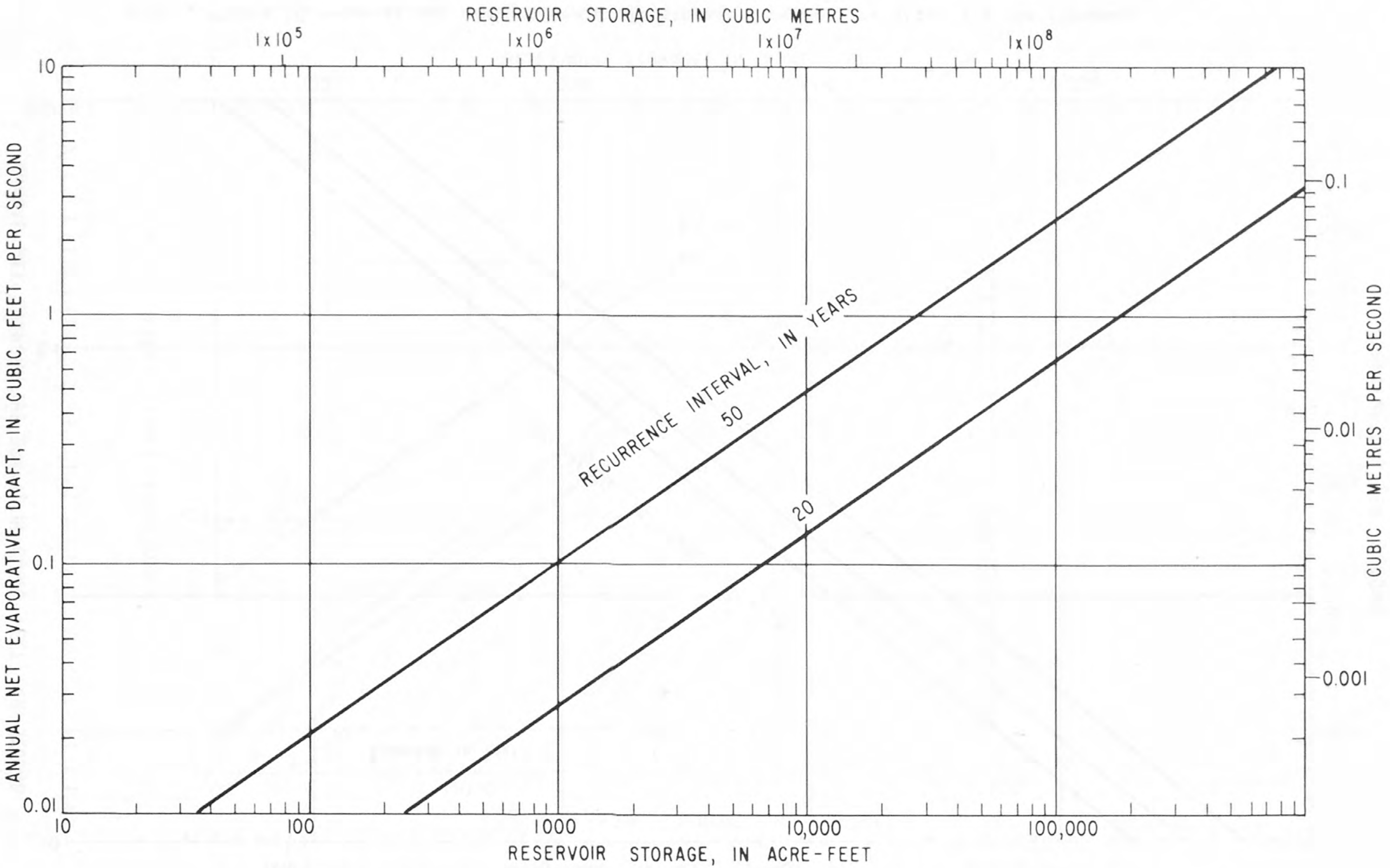

Figure 11.--Annual net evaporative draft-storage-frequency relation for the Coastal Plain.

To estimate the evaporative loss from a reservoir in the Piedmont or Coastal Plain, it is necessary to refer to the map, plate 1, to find in which province the site lies. Then, using the applicable relation for the desired design recurrence interval, determine a corresponding evaporative draft. This evaporative draft must be subtracted from the total draft available from a reservoir with the given storage capacity. It may be necessary to provide for additional storage, if, after the evaporative draft is subtracted, the available draft, for supply purposes, is not adequate to meet the demand.

Continuing our example of a hypothetical reservoir on Hunting Creek north of Statesville, we can enter the relation for the 50-year recurrence interval on figure 10 at the storage capacity of 54,300 acre-ft (67 hm^3) which we determined earlier. The corresponding evaporative draft is slightly more than 3.5 ft^3/s (0.1 m^3/s). Thus, the reliable draft would be 76.5 ft^3/s (2.2 m^3/s) instead of 80 ft^3/s (2.3 m^3/s). If this reduction is significant, the designer might wish to increase the storage in the lake to allow a draft of 80 ft^3/s (2.3 m^3/s) after the evaporation loss is subtracted.

Two important conclusions may be drawn from the analysis of evaporation data. Annual lake evaporation losses are significant in the Piedmont and Coastal Plain of North Carolina, but not in the mountains and, all other things being equal, evaporative losses are proportionately smaller for a large reservoir than for a small one.

Figure 12 illustrates the second conclusion. The two lines represent data from the Piedmont. The line on the top is drawn through data computed for a reservoir impounding a stream with a mean annual runoff of 500 acre-ft (0.62 hm^3), which is a mean annual flow of less than 0.7 ft^3/s (0.02 m^3/s). The line on the bottom is through data for a reservoir on a stream with a mean annual runoff of 100,000 acre-ft (123 hm^3). The proportionally higher evaporative draft from the reservoir impounding the smaller stream indicates that a large reservoir on a stream is preferable to a number of small reservoirs on the stream that, collectively, would furnish the same draft. Farm ponds, for example, lose proportionately more water to evaporation than do large impoundments. Figure 13 illustrates the same conclusion. However, the net evaporative draft in the Coastal Plain is about 20 percent less than that in the Piedmont.

The evaporation analyses illustrated in figures 8-11 required several assumptions. We assumed that the maximum net evaporation for a given recurrence interval occurs during the drought of the same recurrence interval. This assumption may not be strictly valid, however, since net lake evaporation tends to be greatest during dry, hot periods, we believe it will lead to useful results. We also assumed that the net-evaporation rate is representative of that which occurs during the critical drought period, which may be longer or shorter than a year. In addition, while a significant amount of evapotranspiration may be salvaged, we feel that the water thus saved tends to make our estimates of evaporative draft more conservative. That is, in spite of the errors involved, the actual evaporative draft will probably be less than that estimated from the relations in this report.

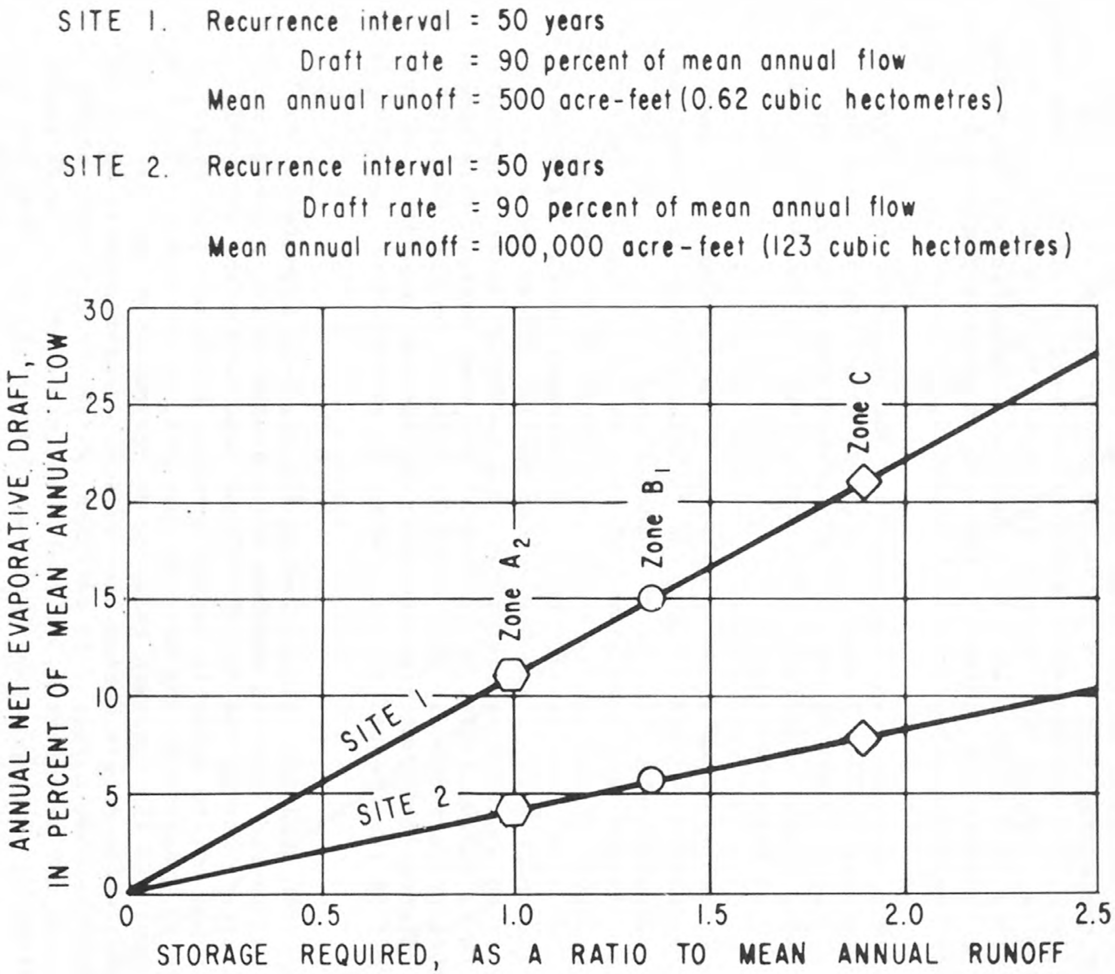

Figure 12.--Comparison of evaporative draft versus storage for two sites in the Piedmont, having mean annual runoffs of 500 and 100,000 acre-feet (.62 and 123 cubic hectometres), respectively.

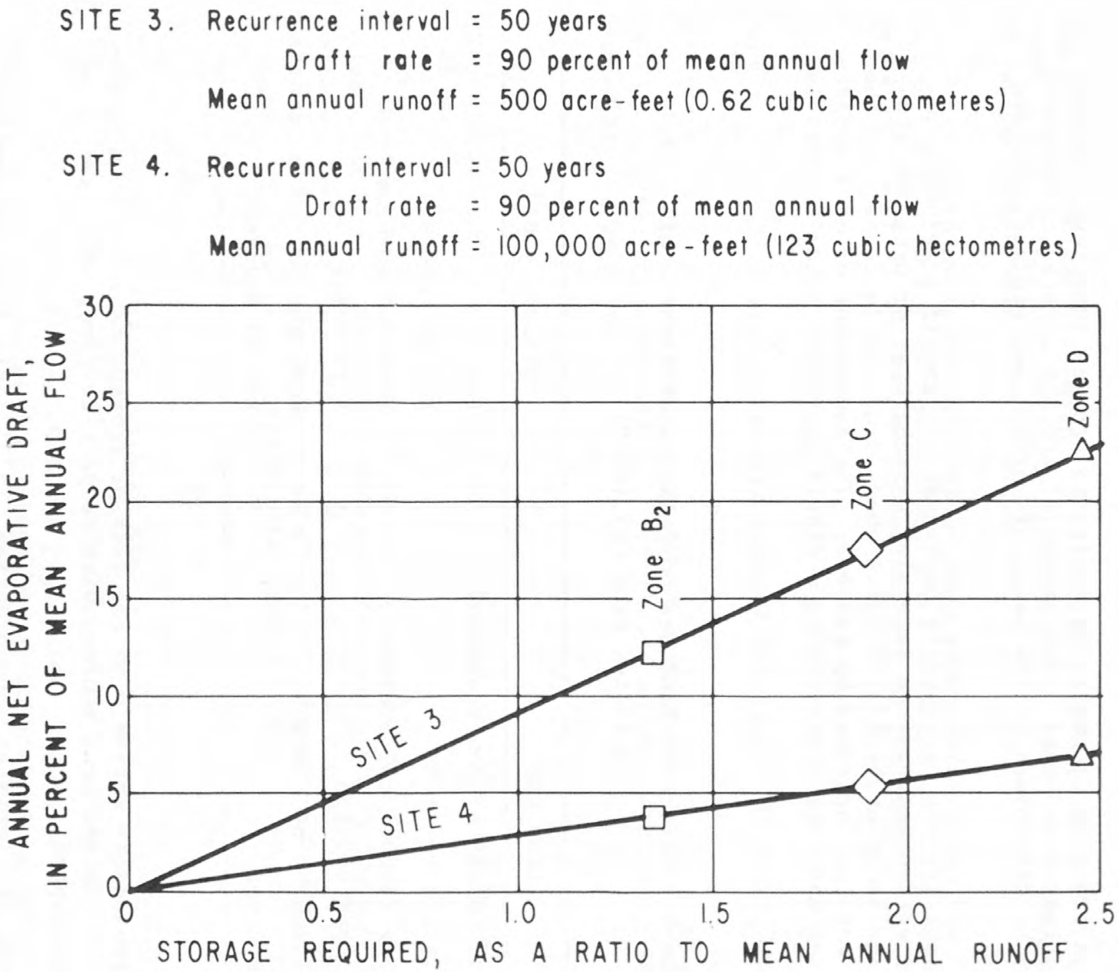

Figure 13.--Comparison of evaporative draft versus storage for two sites in the Coastal Plain having mean annual runoffs of 500 and 100,000 acre-feet (.62 and 123 cubic hectometres), respectively.

Sedimentation

It is common practice in reservoir design to provide additional storage for the accumulation of sediment. The amount of storage devoted to sediment accumulation may be determined on the basis of current and estimated future sediment yields.

Reservoir capacity may be severely decreased in time if previously untouched upstream watersheds undergo extensive agricultural or urban development. The average sediment yield from watersheds tends to increase with the encroachment of man, as indicated by table 2. The equivalent of many decades of natural erosion may take place during a single year from areas cleared for construction.

Table 2.--Effect of land use on relative sediment yield

[Modified from Guy (1970)]

Land use	Sediment yield
A. Natural forest or low grassland	Low
B. Heavily grazed areas	Low to moderate
C. Cropping (annual cultivation)	Moderate to heavy
D. Urban construction	Very heavy
E. Stabilization of channel	Moderate
F. Stable urban	Low to moderate

To make a reasonable estimate of the loss of storage capacity in a reservoir, the state of the sediment source, with respect to time, will have to be recognized and evaluated.

H. R. Malcom, Jr. (written communication, 1973) derived several sediment discharge relations based on the degree of disturbance of watersheds in the Piedmont areas of the Atlantic-slope river basins in Maryland, Washington, D. C., Virginia, and North Carolina. These relations are presented here as a guide to illustrate the effects sediment deposition will have on the draft-storage relations. He states on page 6:

"Basins which are heavily forested, with few roads and little agricultural, industrial, or residential usage, are classified as Wooded basins. For this case sediment discharge can be estimated from the equation:

$$S = 0.068\ A^{0.80} \tag{1}$$

where S is sediment discharge in acre feet per year and A is the contributory drainage area in square miles. The applicable range of drainage area is 4 to 300 square miles [10.4 to 777 km^2].

Basins in agricultural regions with some wooded areas but with no significant urban or suburban development are classified as Rural basins. For these areas sediment discharge can be estimated from the equation:

$$S = 0.355\ A^{0.99} \tag{2}$$

The applicable range of drainage area is 0.3 to 100 square miles [0.78 to 259 km^2].

Basins in stable urban areas where development is essentially complete are classified as Urban basins. For this case sediment discharge can be estimated by the equation:

$$S = 2.96\ A^{0.67} \tag{3}$$

The applicable range of drainage area is 0.8 to 70 square miles [2.1 to 181 km^2].

Basins that are subjected to a high degree of disturbance, such as intensive construction activity, are classified as Severely Exposed basins. An area of disturbance comprising as little as 11 percent of the gross watershed area is sufficient to produce a sediment discharge conforming to the classification. For this case sediment discharge can be estimated by the equation:

$$S = 34.5\ A^{0.84} \tag{4}$$

The applicable range of drainage area is 0.0025 to 10 square miles [0.006 to 25.9 km^2]."

These relations are shown in figure 14. The range in sediment rates under these various states of disturbance can best be illustrated by considering a drainage basin of 10 mi^2 (25 km^2). Using the severely exposed classification, the sediment rate would be 240 acre-feet per year (0.3 hm^3 per year), whereas the sedimentation rate from a wooded basin would be only 0.4 acre-feet per year (493 m^3 per year).

The derivation of the relations have several inherent shortcomings and are discussed by Malcom on page 16 as follows:

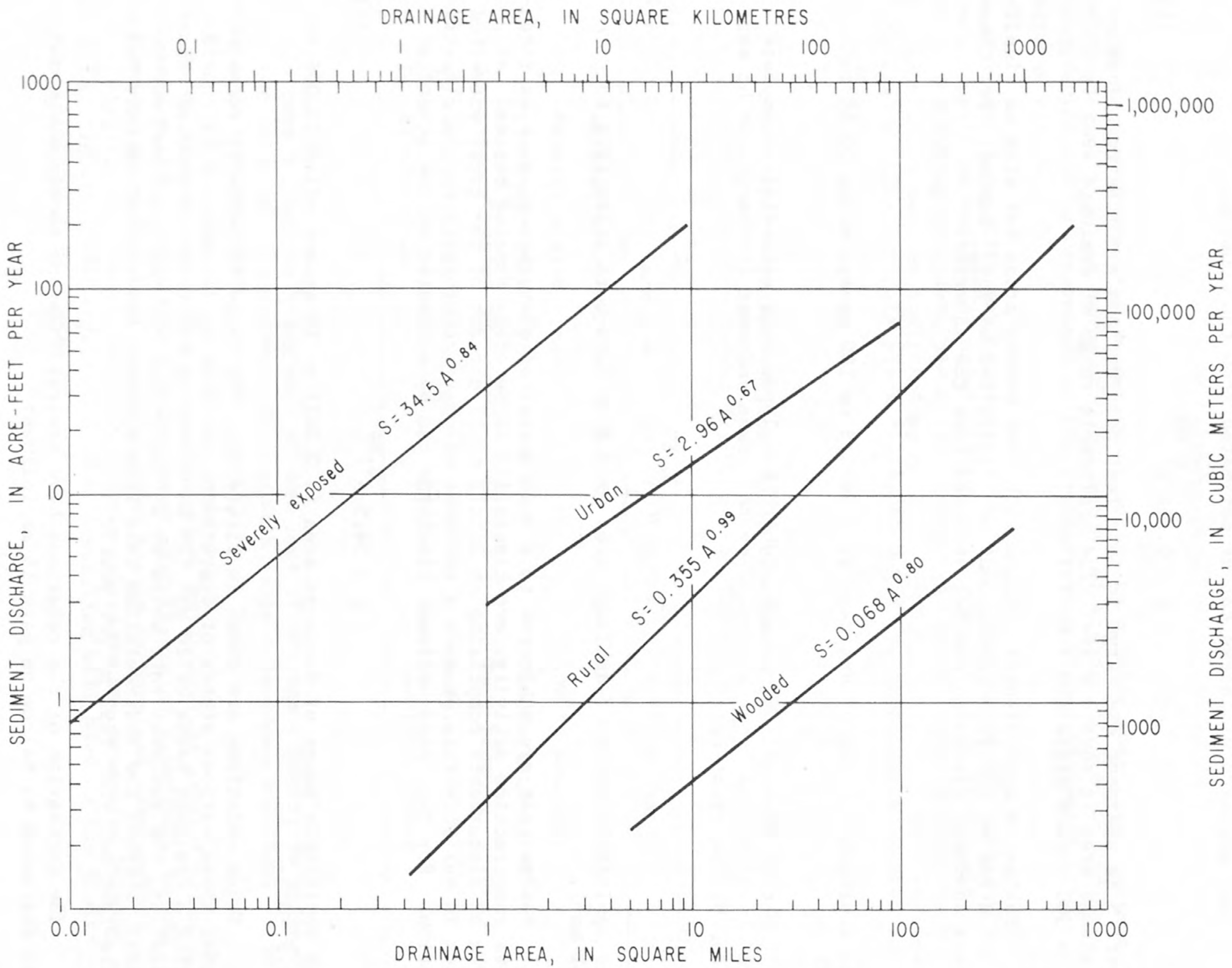

Figure 14.--Relation between sediment discharge, S, and drainage area, A (Modified from Malcom, 1973).

"Many of the observations used have been taken over relatively short time periods. Insofar as the writer can determine, no effort has been made to adjust sediment levels for abnormal rainfall, rainfall impact energy or streamflow. Accordingly, some error will be present in short-term measurements because sediment quantities will be affected by the amount and distribution of rainfall during the period of observation.

In several basins, multiple observations of sedimentation have been made for the same reference point. In such cases the variation of the measurement with time may be observed, and it is found to be large. Whether this variation is due to changes in surface disturbance in the basin or to differences in rainfall experience, or both, is not known. It does serve to illustrate the degree to which sediment discharge is likely to vary. Thus, the use of the predicting expressions developed here for planning purposes is justified."

In our example for Hunting Creek, the basin may be classified as a wooded basin. Since the drainage area is 100 mi^2 (259 km^2), the annual sediment discharge is 2.7 acre-ft/year (3,330 m^3/year) estimated from equation 1 or from the appropriate curve on figure 14. Thus, if the designer wished to insure his reliable draft for a period of 50 years, he would have to provide an additional 135 acre-ft or .17 hm^3/year (2.7 acre-ft/year x 50 years) of storage that would fill with sediment by the end of the 50 year period. If the basin changed to an urban classification, the annual sediment discharge would be 65 acre-ft/year (.08 hm^3/year) estimated from equation 3, or an increase by a factor of 24. These relations, applicable to the Piedmont, should be used in the remaining part of the State only with prior consideration of their limitations.

Seepage

Seepage is usually insignificant in reservoirs underlain by competent rock or by clay or silty soils. It may become a problem, however, where there are open fault zones in the rock beneath the dam, where the reservoir is underlain by cavernous limestone, or where the deposits under the reservoir consist of continuous sandy or gravel layers extending downstream from the dam. Methods to determine seepage-loss rates include graphical, semigraphical, electric analog, and digital models. A widely used graphical method consists of fitting a flow net to the boundary conditions of the site. A flow net is a two-dimensional graph composed of two families of curves: flow lines or streamlines that indicate how water travels, and equipotential lines that join points of the same potential (pressure head). Once a flow net has been established, the ground-water flow can be computed directly from the geometry of the net, using the equation:

$$Q = \frac{Kmhl}{n} \qquad (5)$$

where Q is the discharge, K is the hydraulic conductivity, m is the number of channels formed by the flow lines, n is the number of squares between two adjacent flow lines, h is the total head loss, and l is the length of the dam.

Although accurate seepage-loss estimates require a thorough knowledge of ground water and geologic conditions at the site, one can gain some feeling for the amount of seepage from a proposed reservoir by considering a simplified example. Figure 15 illustrates a typical flow net beneath a reservoir dam. Although differences in construction of the dam or any nonhomogeneity of the underlying soil or rock could drastically change this flow net, we derived a general relation for this idealized situation that will enable the user to make an order-of-magnitude estimation of seepage losses from a proposed reservoir.

In figure 15, m = 5 and n = 15. Therefore; from equation 5:

$$Q = \frac{5Khl}{15}$$

or

$$Q = \frac{Khl}{3} \qquad (6)$$

The total head loss, h, is the vertical distance between the water surface in the reservoir and the water surface in the stream downstream from the dam. K is the hydraulic conductivity, which may be estimated from figure 16.

Suppose, for our example on Hunting Creek, that the dam must be 1,000 feet (305 m) long, it will increase the height of the water 15 feet (4.6 m); and the hydraulic conductivity for the clay soil in the area is 10^{-2} ft/day (0.003 m/day). From equation 6,

$$Q = \frac{khl}{3} = \frac{(10^{-2})\ (15)\ (1000)}{3} = 50\ ft^3/day$$

or

$$Q = \frac{1}{86,400}\ (50) = 0.58 \times 10^{-3}\ ft^3/s = (1.6 \times 10^{-5}\ m^3/s)$$

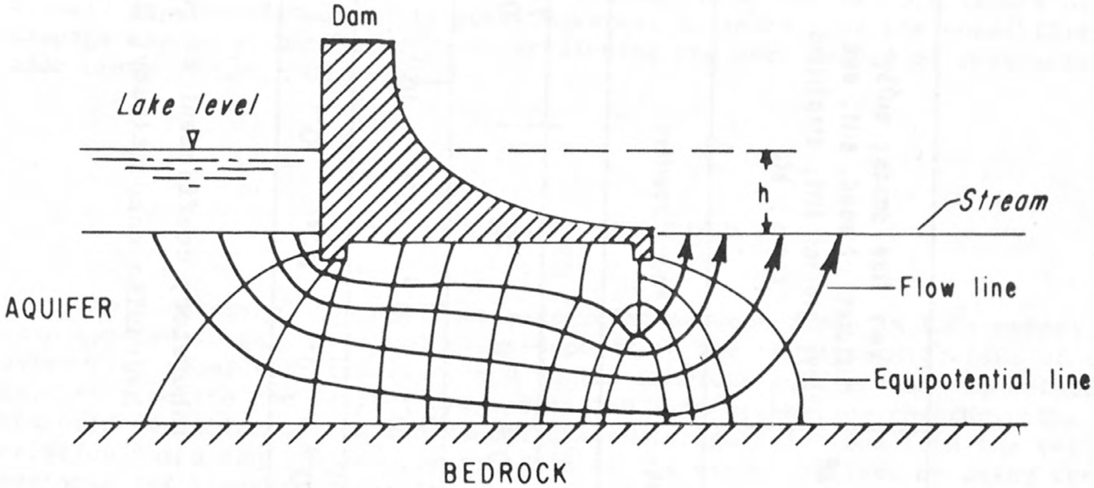

Figure 15.--Flow net under a dam on a permeable foundation.

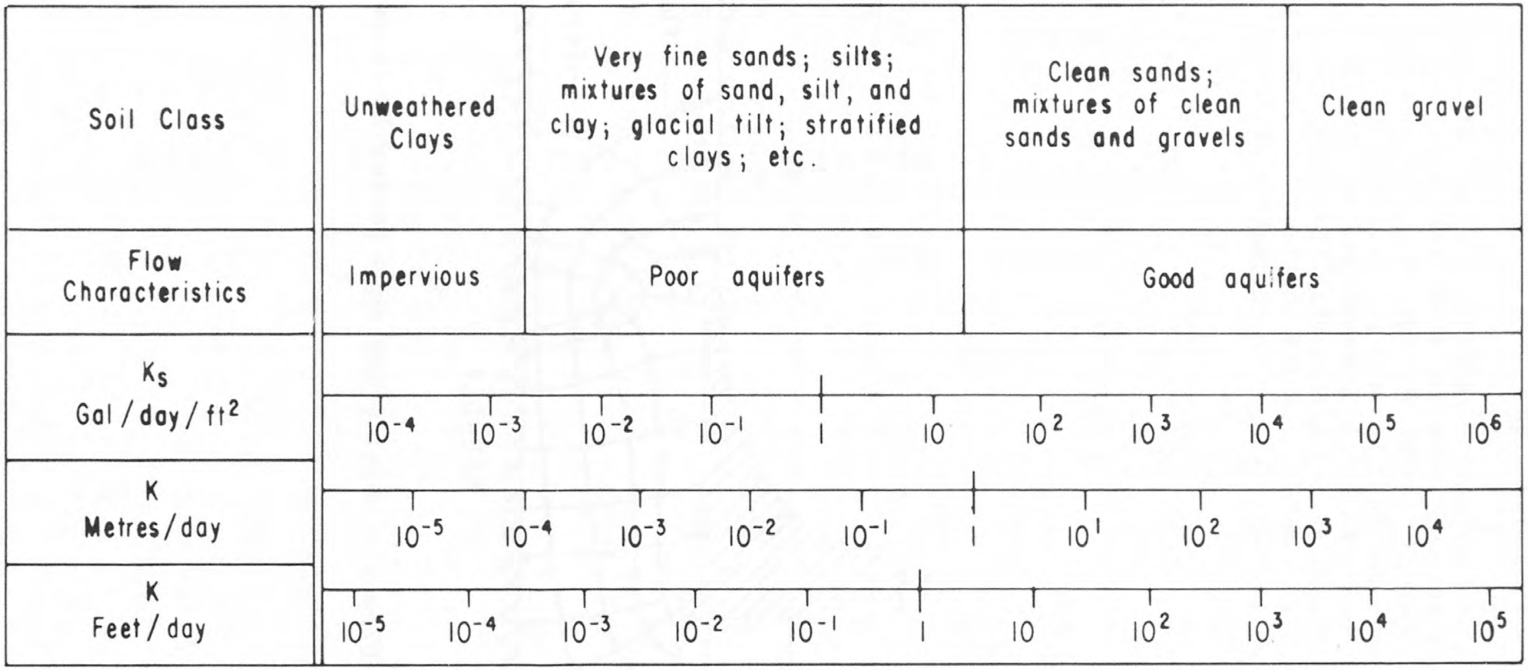

Figure 16.--Laboratory coefficient of permeability, K_s, and hydraulic conductivity, K, (Modified from Todd, 1955).

This seepage is obviously insignificant, but suppose the reservoir was to be built on a sandy soil more typical of that in the Coastal Plain. A representative hydraulic conductivity might be 100 ft/day (30.5 m/day). Thus, using equation 6 again,

$$Q = \frac{(100)\ (15)\ (1000)}{3} = 500{,}000\ ft^3/day$$

or

$$Q = \frac{500{,}000}{86{,}400} = 5.8\ ft^3/s = (0.16\ m^3/s)$$

This seepage would be a significant loss for our hypothetical reservoir and could lead to another problem. Water flowing at this rate through the foundation might cause erosion at the downstream side of the dam, endangering the stability of the structure.

This example should not be interpreted as indicating that reservoirs are impractical in the Coastal Plain because of seepage losses. Actually, most of the Coastal Plain is underlain at various depths by one or more layers of relatively impermeable clay. It does, however, indicate that the possibility of seepage may be a consideration in predicting the performance of reservoirs in some areas of North Carolina.

ASSUMPTIONS AND ERRORS

The accuracy of the draft-storage relations contained in this report, when applied to an individual site, depends on the representativeness of the streamflow records at the site, and on the inherent accuracy of the method used to generate the draft-storage relation from streamflow records. The standard deviation of the individual draft-storage relations from the regional relation for a zone is an approximation of the error obtained by using the regional relations to determine the draft-storage requirements of a reservoir. Table 3 lists the standard deviation in percent of the storage required for selected draft rates. The percentages are high in the lower draft rates, reflecting the fact that the technique we used for regionalization does not account for all of the extreme variability in low flow regimes in the State. Large percentage standard deviations at lower draft rates do not, however, involve much total storage. For example, the 95 percent standard deviation in zone A for a draft rate of 30 percent and a 10 year recurrence interval is only 1.4 percent of the mean annual runoff. Table 4 tabulates the same standard deviations computed as a percentage of the mean annual runoff.

Table 3.--Standard deviation, in percent, of the storage required for corresponding draft rates and recurrence intervals

Recurrence interval, in years		Zone A			Zone B			Zone C			Zone D		
		10	20	50	10	20	50	10	20	50	10	20	50
Draft rate, in percent of mean annual flow	10	-	-	-	-	-	-	-	85	60	85	70	85
	20	-	-	-	-	-	145	60	50	35	30	35	55
	30	95	80	65	110	100	75	40	35	30	20	40	50
	40	50	40	45	65	65	50	25	20	20	15	35	50
	50	35	30	25	40	35	40	20	20	25	25	30	35
	60	25	25	25	40	35	30	15	15	15	25	25	25
	70	30	25	25	30	25	20	15	10	10	20	25	25
	80	20	20	20	15	15	15	10	10	10	20	20	25
	90	15	15	20	15	15	15	10	10	10	25	30	35
	95	15	20	20	15	15	15	15	15	15	30	50	35

Leaders indicate negligible storage required.

Table 4.--Standard deviations of the storage required, expressed as a percent of mean annual runoff

Recurrence interval, in years		Zone A			Zone B			Zone C			Zone D		
		10	20	50	10	20	50	10	20	50	10	20	50
Draft rate, in percent of mean annual flow	10	-	-	-	-	-	-	-	1.0	1.1	1.6	1.9	3.9
	20	-	-	-	-	-	1.9	2.0	2.2	2.0	2.0	2.7	6.0
	30	1.4	1.8	2.1	2.0	2.7	3.0	3.0	2.4	3.0	2.0	5.4	11.0
	40	2.1	2.1	3.6	3.0	4.0	4.0	3.0	3.0	4.0	2.0	8.0	14.0
	50	2.7	2.9	3.0	4.0	4.0	6.0	3.0	4.0	7.0	6.0	11.0	17.0
	60	3.0	3.9	5.0	5.0	7.0	9.0	4.0	5.0	7.0	10.0	14.0	17.0
	70	5.0	6.0	8.0	7.0	9.0	9.0	6.0	6.0	8.0	13.0	18.0	21.0
	80	7.0	8.0	10.0	8.0	10.0	12.0	7.0	8.0	11.0	18.0	24.0	35.0
	90	10.0	13.0	20.0	13.0	16.0	22.0	12.0	16.0	23.0	32.0	52.0	88.0
	95	15.0	25.0	32.0	18.0	28.0	36.0	23.0	34.0	44.0	56.0	155.0	150.0

Leaders indicate negligible storage required.

The evaporative draft relations are based on the following assumptions, one of which was discussed earlier:

1. That the adjusted lake evaporation data collected during the 10-year study at Lake Michie is representative of long-term lake evaporation in the Coastal Plain and Piedmont of North Carolina.

2. That the critical design-period drought and the maximum evaporation for that recurrence interval occur simultaneously, and the annual evaporation is the same as the evaporation during the critical period, which may be longer or shorter than 1 year.

In view of these assumptions, we recommend that the evaporative-draft relations be used only for reconnaissance-level investigations or where more reliable information is not available.

The sedimentation relations are only empirical approximations drawn from a set of highly variable data. As discussed in the section on sediment these relations should be used only with due consideration of their limitations.

The example illustrating the relative seepage from a reservoir may be used only to gain an idea of the order of magnitude of the flow of water beneath a dam. Stratification of the soil, differences in the geometry of dams, a difference in the relative depth to impermeable rock, or other differences can greatly affect seepage losses.

SUMMARY

The storage required for a specified draft rate not exceeding 95 percent of the mean annual flow can be determined through the use of the draft-storage relations presented in this report. Comparison of relations for different parts of the State indicates that very little storage, 1 percent of the mean annual runoff, is needed in zone A for draft rates not exceeding 30 percent of the mean annual flow, and with deficiencies occurring only once every 50 years, on the average. By contrast, in zone D, at least 20 percent of the mean annual runoff has to be stored to provide for draft rates equivalent to 30 percent of the mean annual flow. When draft rates are 90 percent of the mean annual flow, zone A requires storage equal to the mean annual runoff, but zone D requires 2.4 times the mean annual runoff. The storage requirements in zones B and C are intermediate between these two extremes.

Annual evaporation loss rates for a reservoir having a storage capacity equivalent to two times the mean annual runoff of 500 acre-ft (0.62 hm^3), range from about 17 percent of the mean annual flow in the Coastal Plain to 22 percent in the Piedmont during the worst conditions expected to occur once in 50 years. Also, smaller reservoirs induce more net evaporation per unit of storage due to a disproportionate increase in the ratio of lake surface area to volume as the size of the reservoir decreases.

Estimated sedimentation rates in reservoirs in the Piedmont range from 240 acre-ft (296,000 m^3) per year for a severely exposed drainage basin of 10 mi^2 (25 km^2) to 0.4 acre-ft (493 m^3) per year in a wooded basin of the same size.

Seepage losses can be prevented by knowledge of the geologic and ground-water conditions at the site. The flow-net analysis presented is intended for illustrative purposes only. Other means of evaluating potential seepage are available, each one pertinent to the particular dam design.

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16. Abstracts

To aid in site selection, planning, and managing the development of reservoirs in North Carolina, draft-storage-frequency relations were developed for each of four regions covering nearly all of the State. These relations, derived through analysis of streamflow data collected at 142 long-term gaging stations, enable the user to estimate the storage capacities that a planned or existing reservoir must have to furnish the draft he needs with a 2, 5, or 10 percent change of failure within any one year. Or, working from a known reservoir capacity, the user can estimate the allowable draft. The relations show that a draft equal to 90 percent of the mean annual flow of a stream requires a reservoir large enough to store from one to nearly two and one half times the mean annual runoff of the stream at that point.

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