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TECHNICAL GUIDANCE MANUAL

FOR

PERFORMING WASTELOAD ALLOCATION

BOOK VI

DESIGN CONDITIONS

CHAPTER I

STREAM DESIGN FLOW FOR STEADY-STATE MODELING

SEPTEMBER 1986

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

OFFICE OF WATER

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MEMORANDUM

Subject: Technical Guidance Manual for Performing Wasteload Allocations Book VI, Design Conditions: Chapter 1 - Stream Design Flow for Steady-State Modeling

From: William A. Whittington, Director
Office of Water Regulations and Standards (WH-551)

To: Addressees

Attached, for national use, is the final version of the Technical Guidance Manual for Performing Wasteload Allocations, Book VI, Design Conditions: Chapter 1 - Stream Design Flow for Steady-State Modeling. This manual replaces the interim stream design flow recommendations included in Appendix D of our Technical Support Document for Water Quality-based Toxics Control, September, 1985. We are sending extra copies of this manual to the Regional Waste Load Allocation Coordinators for distribution to the States to use in conducting waste load allocations.

If you have any questions or desire additional information please contact Tim S. Stuart, Chief, Monitoring Branch, Monitoring and Data Support Division (WH-553) on (FTS) 382-7074

Attachment

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SECTION 1. INTRODUCTION

1.1 Purpose

The purpose of this guidance is to describe and compare two methods that can be used to calculate stream design flows for any pollutant or effluent for which a two-number water quality criterion (WQC) for the protection of aquatic life is available. The two methods described are:

1. The hydrologically-based design flow method recommended for interim use in the Technical Support Document for Water Quality-based Toxics Control (1); and

2. A biologically-based design flow method that was developed by the Office of Research and Development of the U.S. EPA.

1.2 Background

National water quality criteria for aquatic life (2) are derived on the basis of the best available biological, ecological and toxicological information concerning the effects of pollutants on aquatic organisms and their uses (3,4). To account for local conditions, site-specific criteria may be derived whenever adequately justified (4). In addition, criteria may be derived from the results of toxicity tests on whole effluents (1). National, site-specific, and effluent toxicity criteria specify concentrations of pollutants, durations of averaging periods, and frequencies of allowed exceedences. If these criteria are to achieve their intended purpose, decisions concerning not only their derivation, but also their use, must be based on the biological, ecological, and toxicological characteristics of aquatic organisms and ecosystems, and their uses, whenever possible.

National, site-specific, and effluent toxicity criteria are expressed as two concentrations, rather than one, so that the criteria can more accurately reflect toxicological and practical realities (1 - 4):

a. The lower concentration is called the Criterion Continuous Concentration (CCC). The CCC is the 4-day average* concentration of a pollutant in ambient water that should not be exceeded more than once every three years on the average.

b. The higher concentration is called the Criterion Maximum Concentration (CMC). The one-hour average concentration in ambient water should not exceed the CMC more than once every three years on the average.

Use of aquatic life criteria for developing water quality-based permit limits and for designing waste treatment facilities requires the selection of an appropriate wasteload allocation model. Dynamic models are preferred for the application of aquatic life criteria in order to make best use of the specified concentrations, durations, and frequencies (2). If none of the dynamic models can be used, then an alternative is steady-state modeling. Because steady-state modeling is based on various simplifying assumptions, it is less complex, and may be less realistic, than dynamic modeling. An important step in the application of steady-state modeling to streams is the selection of the design flow.

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* Although a 4-day averaging period should be used for the CCC in most situations, an averaging period as long as 30 days may be used in situations involving POTWs designed to remove ammonia where low variability of effluent pollutant concentration and resultant concentrations in receiving waters can be demonstrated. In cases where low variability can be demonstrated, longer averaging periods for the ammonia CCC (e.g., a 30-day averaging period) would be acceptable because the magnitudes and durations of excursions above the CCC would be sufficiently limited (5).

One way of using the CCC and the CMC in steady-state modeling requires calculation of the two design flows (i.e., a CCC design flow and a CMC design flow). Whether the CCC and its design flow or the CMC and its design flow is more restrictive, and therefore controlling, must be determined individually for each pollutant of concern in each effluent because the CCC and CMC are pollutant-specific, whereas the two design flows are specific to the receiving waters.

Wasteload allocation modeling for streams usually uses flow data obtained from the United States Geological Survey gaging stations. If sufficient flow data are not available for a stream of interest, data must be extrapolated from other streams having hydrologic characteristics similar to those of the stream of interest.

1.3 Scope

This guidance is limited to (a) describing two methods that can be used for calculating stream design flows for any pollutant or effluent for which a two-number aquatic life water quality criterion is available, and (b) making recommendations concerning the use of these methods in steady-state modeling.

The water quality criterion for dissolved oxygen was revised very recently and the assessment of the appropriate design flow for dissolved oxygen modeling has not yet been completed. Therefore, the state-specified design flows that traditionally have been used for conventional pollutants should not be affected by this guidance.

State-specified design flows necessarily preempt any design flow that is recommended in this guidance unless the state chooses to use either of these two methods. The choice of design flows for the protection of human health has been discussed in the Technical Support Document for Water Quality-based Toxics Control (1).

Aquatic life criteria of some pollutants are affected by environmental variables such as water temperature, pH, and hardness. In addition to the design flow, such other stream variables as pH and temperature might increase or decrease the allowable in-stream concentrations of some pollutants (e.g., ammonia). The need to consider other variables when determining the design flow for those pollutants should be emphasized. This document will provide guidance for the calculation of design flow; pH, temperature, and hardness will likely be addressed later.

SECTION 2. HYDROLOGICALLY-BASED DESIGN FLOW METHOD

2.1 Introduction

The purpose of this section is to describe the hydrologically-based design flow calculation method and provide some examples of its use. The Technical Support Document for Water Quality-based Toxics Control (1) provides Agency guidance on control of both generic and pollutant-specific toxicity and recommended interim use of the hydrologically-based method. In addition, the Agency also recommended (1,2) that the frequencies of allowed exceedences and the durations of the averaging periods specified in aquatic life criteria should not be used directly to calculate steady-state design flows using an extreme value analysis. For example, if a criterion specifies that the four-day average concentration should not exceed a particular value more than once every three years on the average, this should not be interpreted as implying that the 4Q3 low flow is appropriate for use as the design flow.

Because a procedure had not been developed for calculating design flow based on the durations and frequencies specified in aquatic life criteria, the U.S. EPA recommended interim use of the 1Q5 and 1Q10 low flows as the CMC design flow and the 7Q5 and 7Q10 low flows as the CCC design flow for unstressed and stressed systems, respectively (1). Further consideration of stress placed on aquatic ecosystems resulting from exceedences of water quality criteria indicates that there is little justification for different design flows for unstressed and stressed systems. All ecosystems have been changed as a result of man's activities. These changes have resulted in stress being placed on the ecosystem before a pollutant stress. In addition, it is not possible to predict the degree of pollutant stress when one considers both the timing and variability of flows, effluent discharges, and ecosystem sensitivity and resilience.

2.2 Rationale

The following provides a rationale for the hydrologically-based design flow calculation method:

- About half of the states in the nation use 7Q10 as the design low flow.
- The log-Pearson Type III flow estimating technique or other extreme value analytical techniques that are used to calculate flow statistics from daily flow data are consistent with past engineering and statistical practice.
- Most users are familiar with the log-Pearson Type III flow estimating procedure and the USGS provides technical support for this technique.
- Analyses of 60 rivers indicate that, on the average, the biologically-based CMC and CCC design flows are nearly equal to the 1Q10 and the 7Q10 low flows.

2.3 Example Cases

In order to illustrate the calculation of hydrologically-based design flows, sixty rivers with flows of various magnitudes and variabilities were chosen from around the country. The 1Q10 and 7Q10 low flows of the sixty rivers are presented in Table 2-1. The list of rivers in this table is arranged in increasing magnitude of the 7Q10 low flows. The estimates of the 1Q10 and 7Q10 low flows were made using the USGS daily flow database and the FLOSTAT program (6) which employs the log-Pearson Type III technique.

The estimates of 1Q10 and 7Q10 low flows could have been made using EPA-ORD's DFLOW program, which uses a simplified version of the log-Pearson Type III method. The simplified version of the log-Pearson Type III estimating technique for any xQy design flow is presented in Appendix A. Although the Log-Pearson Type III is in general use, it should be recognized that there are other distributions that may be more appropriate to use on a case-by-case basis. The hydrologically-based design flow for ammonia is discussed in Appendix B.

Analyses of the 1Q10 and 7Q10 low flows in Table 2-1 indicate that the mean of the ratios of 7Q10 to 1Q10 is 1.3. The median of the ratios is 1.1, whereas the range of the ratios is 1.0 to 3.85. Thus, 7Q10 low flows are generally 10 to 30% greater than the corresponding 1Q10 low flows, although in one case the 7Q10 is 3.85 times greater than the corresponding 1Q10.

Table 2-1. Hydrologically-based design flows (ft^3/sec) for 60 streams

Station ID	River name	State	Period of Record	C/*	Design flow (ft^3/sec) 1Q10	Design flow (ft^3/sec) 7Q10	7Q10 / 1Q10
01657000	Bull Run	VA	1951-82	4.48	0.3	0.4	1.33
02092500	Trent	NC	1951-82	1.77	1.4	1.6	1.14
06026000	Birch Cr	MT	1946-77	1.32	1.7	2.4	1.41
12449600	Beaver Cr	WA	1960-78	1.77	2.4	3.2	1.22
05522000	Iroquois	IN	1949-78	1.33	3.4	3.9	1.15
09490800	N Fk White	AZ	1966-78	1.24	4.8	5.3	1.10
14372500	E Fk Illinois	OR	1942-83	2.03	6.4	6.7	1.05
05381000	Black	WI	1905-83	2.51	5.5	6.7	1.22
10291500	Buckeye	CA	1911-78	1.30	7.1	7.7	1.08
05585000	La Moine	IL	1921-83	1.99	9.3	9.9	1.06
12321500	Boundary Cr	ID	1928-84	1.65	11.7	13.1	1.12
01111500	Branch	RI	1940-82	1.16	8.8	13.3	1.51

Table 2-1 (continued).

Station ID	River name	State	Period of Record	CV*	Design flow (ft³/sec) 1Q10	7Q10	7Q10/1Q10
02138500	Linville	NC	1922-84	1.74	13.4	16.4	1.22
05059000	Sheyenne	ND	1951-81	2.10	15.9	13.3	1.15
02083000	Fishing Cr	NC	1927-82	1.48	17.0	19.4	1.14
01196500	Quinnipiac	CT	1931-84	1.02	17.5	32.3	1.85
02133500	Drowning Cr	NC	1940-78	0.80	38.8	43.4	1.12
06280300	Shoshone	WY	1957-84	1.54	41.8	46.8	1.12
09149500	Uncompahgre	CO	1939-80	0.86	35.6	50.8	1.43
02296750	Peace	FL	1931-84	1.54	49.0	55.3	1.13
07018500	Big	MO	1922-84	2.16	46.4	55.3	1.19
02217500	Middle Oconee	GA	1902-84	1.37	49.4	57.4	1.16
01481000	Brandywine	PA	1912-84	1.17	61.4	67.2	1.09
09497500	Salt	AZ	1925-80	2.05	64.6	68.7	1.06
01144000	White	VT	1915-84	1.43	75.3	85.2	1.13
01600000	N Br Potomac	MD	1939-83	1.42	54.7	61.6	1.13
09359500	Animas	CO	1946-56	1.56	54.8	62.3	1.15
01403060	Raritan	NJ	1904-83	1.64	54.2	67.1	1.24
02413500	L Tallapoosa	AL	1940-51	1.32	72.7	88.3	1.21
01421000	E B Delaware	NY	1915-78	1.41	80.8	89.7	1.11
07288500	Big Sunflower	MS	1936-80	1.42	89.4	91.9	1.03
07013000	Meramec	MO	1923-78	2.41	88.8	92.2	1.05
01531000	Chemung	NY	1915-78	1.91	89.7	97.5	1.09
07096000	Arkansas	CO	1901-81	1.12	107.9	126.1	1.17
09070000	Eagle	CO	1947-80	1.36	116.9	131.0	1.12
01011000	Allegash	ME	1932-83	1.39	124.5	134.1	1.08
03528000	Clinch	TN	1919-78	1.55	128.7	135.2	1.05
13023000	Greys	WY	1937-83	1.16	122.9	144.5	1.18
02424000	Cahaba	AL	1902-78	2.07	151.9	156.4	1.03
05515500	Kankakee	IN	1926-78	0.48	179.0	184.3	1.03
02490500	Bouge Chitto	MS	1945-81	1.89	188.6	191.6	1.02
01315500	Hudson	NY	1908-78	1.10	207.7	211.0	1.02
01610000	Potomac	WV	1939-83	1.48	209.6	220.7	1.05
05386000	Root	MN	1938-61	1.65	229.7	245.6	1.07
02369000	Shoal	FL	1939-82	0.95	280.1	291.4	1.04
07378500	Amite	LA	1939-83	1.98	298.1	303.4	1.02
06465500	Niobrara	NE	1939-83	0.59	160.9	322.0	2.00
02135000	Little Pee Dee	SC	1942-78	0.94	306.7	322.4	1.05
08110200	Brazos	TX	1966-78	1.48	311.6	344.9	1.11
02076000	Dan	VA	1924-52	1.25	329.6	387.3	1.18
03455000	French Broad	TN	1901-78	0.93	473.6	532.2	1.12
05333500	St. Croix	WI	1914-81	0.61	505.9	536.0	1.06
06287000	Bighorn	MT	1935-79	0.82	327.1	557.0	1.70
03107500	Beaver	PA	1957-83	1.10	571.3	594.2	1.04

Table 2-1 (continued).

Station ID	River name	State	Period of Record	CV*	Design flow (ft^3/sec)		7Q10 / 1Q10
					1Q10	7Q10	
13341000	N F Clearwater	ID	1927-68	1.16	529.2	648.6	1.23
07341500	Red	AR	1928-81	1.41	691.0	769.2	1.11
02350500	Flint	GA	1930-58	1.00	207.8	799.8	3.85
01536500	Susquehanna	PA	1901-83	1.34	782.0	814.3	1.04
01100000	Merrimack	MA	1924-83	1.01	270.2	929.3	3.44
14233400	Cowlitz	WA	1968-78	0.93	901.5	968.7	1.07

*CV = Coefficient of Variation

SECTION 3. BIOLOGICALLY-BASED DESIGN FLOW METHOD

3.1 Introduction

The purpose of this section is to describe the biologically-based design flow calculation method and provide some examples of its use. This method was developed by the Office of Research and Development of the U.S. EPA in order to provide a way of directly using EPA's two-number aquatic life water quality criteria (WQC) for individual pollutants and whole effluents to calculate the design flow for performing a wasteload allocation using steady-state modeling. The two-number WQC are in the intensity-duration-frequency format, in that they specify intensity as criteria concentrations, duration as averaging periods, and frequency as average frequency of allowed excursions. Because the flow of, and concentrations of pollutants in, effluents and streams are easily considered in terms of intensity, duration, and frequency, use of this format for expressing WQC allows a direct application to effluents and streams.

Because steady-state modeling assumes that the composition and flow of the effluent of concern is constant, the ambient (instream) concentration of a pollutant can be considered to be inversely proportional to stream flow. Thus by applying a specified averaging period and frequency to a record of the historical flow of the stream of concern, the design flow can be calculated as the highest flow that will not cause exceedences to occur more often than allowed by the specified average frequency, based on historical data. The allowed exceedences are intended to be small enough and far enough apart, on the average, that the resulting small stresses on aquatic organisms will not cause unacceptable effects, except in those cases when a drought itself would cause unacceptable effects.

The averaging periods specified in national water quality criteria are one hour for the CMC and four days for the CCC. The primary use of the averaging periods in criteria is for averaging ambient concentrations of pollutants in receiving waters in order that the averages can be compared to the CMC and CCC to identify "exceedances", i.e., one-hour average concentrations that exceed the CMC and four-day average concentrations that exceed the CCC. However, in steady-state modeling, flow is averaged over a given period to identify "non-exceedences", i.e., average flows that are below a specified flow.

Use of the terms "exceedance" and "non-exceedence", neither of which are in the dictionary, can be a cause of confusion. Water quality criteria are usually expressed as upper limits on concentrations in ambient water and the periods of concern are when the ambient concentration exceeds a criterion concentration, i.e., when there is an exceedence. In steady-state modeling, the averaging is of flows, not concentrations. Because a low flow results in a high pollutant concentration, the period of concern for flow is when the flow is less than the design flow, i.e., when there is a non-exceedance of a given flow. A non-exceedence of a design flow corresponds to an exceedence of a criterion. Use of the non-directional term "excursion", which is in the dictionary, avoids this confusion. Use of the term "excursion" also avoids the problem that some water quality criteria, such as those for dissolved oxygen and low pH, must be stated as lower limits, not upper limits. An exceedence of a dissolved oxygen criterion is favorable, not unfavorable. "Excursion", in this guidance manual, will henceforth be used to imply an unfavorable condition, e.g., a low flow or a pollutant concentration a an upper limit or below a lower limit.

The national water quality criteria specify that, if R is the calculated number of excursions occurring in a period of S years, then S/R should be equal to or greater than 3 years. Most excursions will be small and most aquatic ecosystems will probably recover from the resulting minor stress in less than three years. However, the three years is meant to be longer than the average recovery period so that ecosystems cannot be in a constant state of recovery even if excursions are evenly spaced over time.

Although 3 years appears to be appropriate for small excursions that are somewhat isolated, it appears to be excessively long when many excursions occur in a short period of time, such as would be caused by a drought. Droughts are rare events, characterized by long periods of low flow and should not be allowed to unnecessarily lower design flows. Although droughts do severely stress aquatic ecosystems, both directly, because of low flow, and indirectly, because of the resulting high concentrations of pollutants, many ecosystems apparently recover from severe stresses in more than 5, but less than 10 years (1). Because it is not adequately protective to keep ecosystems in a constant state of recovery, 15 years seems like an appropriate stress-free period of time, on the average, to allow after a severe stress caused by a drought situation. Because three years are allowed for each excursion on the average, counting no more than 5 excursions for any low flow period will provide no more than 15 years, on the average, for severe stresses caused by droughts. Thus, for each low flow period, the number of excursions cannot be less than 1.0 or greater than 5.0. The maximum duration of a low-flow period was set at 120 days because it is not too uncommon for excursions to occur within 120 days of each other, whereas it is very rare for excursions to occur during days 121 to 240 after the beginning of a low-flow period.

Figure 3-1 illustrates the features of the biologically-based design flow calculation method. Intervals a-b and c-d are excursion periods and each day in these intervals is part of an average flow that is below the design flow. The number of excursions in an excursion period is calculated as the number of days in the excursion period divided by the duration (in days) of the averaging period (e.g., 1 day for the CMC and 4 days for the CCC). A low-flow period is defined as one or more excursion periods occurring within a 120-day interval. As discussed above, if the calculated number of excursions that occur in a 120-day low-flow period is greater than 5, the number is set at 5 for the purposes of calculating the design flow.

Because biologically-based design flows are based on the averaging periods and frequencies specified in water quality criteria for individual pollutants and whole effluents, they can be based on the available biological, ecological, and toxicological information concerning the stresses that aquatic organisms, ecosystems, and their uses can tolerate. The biologically-based calculation method is flexible enough to make full use

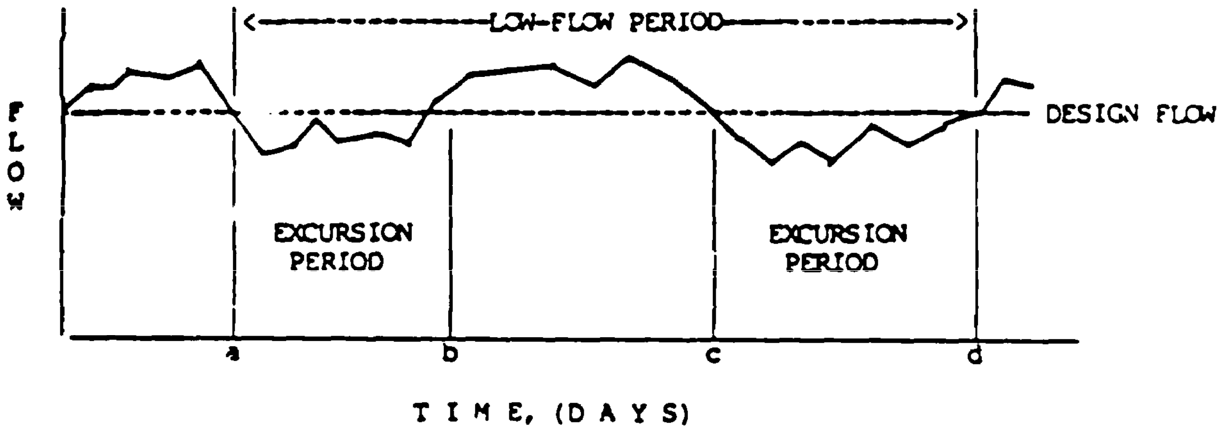

Figure 3-1: Illustration of biologically-based design flow

of special averaging periods and frequencies that might be selected for specific pollutants (e.g., ammonia) or in site-specific criteria. This method is empirical, not statistical, because it deals with the actual flow record itself, not with a statistical distribution that is intended to describe the flow record.

In addition, this method provides an understanding of how many excursions of the CCC or CMC are likely to occur, and during what time of the year, based on actual historical flow data. Thus, it is possible to examine the pattern and magnitudes of what would have been historical excursions. This method makes it clear that criteria concentrations should not be interpreted as values that are never to be exceeded "at any time or place" in the receiving waters. An understanding of what level of protection actually is provided should aid in the use of criteria.

3.2 Procedure

Although the calculation procedure described in Appendix C might look complicated, it merely consists of a sequence of steps that are quite simple. Because flow records usually consist of daily flows for 20 to 80 years, manual calculation of design flow is very time-consuming. The DFLOW computer program (Appendix D) will calculate biologically-based design flows and display the dates, durations, and magnitudes of the excursions within each low flow period.

The CMC and CCC design flows are calculated in almost the same manner. The differences result from the fact that the CMC is expressed as a one-hour average, whereas the CCC is expressed as a four-day average. However, the flow records that are available consist of one-day average flows. For streams with naturally occurring low flows, calculation of the CMC design flow from one-day averages, rather than one-hour averages, should be reasonably acceptable because naturally occurring low flows of receiving streams are usually very similar from one hour to the next. In regulated streams, such as those affected by hydroelectric or irrigation projects, hour-to-hour variation of low flows could be significant and in those situations, use of hourly values, when available, is appropriate. Both the pollutant concentrations and the flows of most effluents are expected to change much more from one hour to the next than the naturally occurring flows of streams.

3.3 Rationale

The following provides a rationale for the biologically-based design flow calculation method:

- It allows the use of the new two-number WQC for aquatic life in the calculation of design flow. If water quality criteria for aquatic life are to achieve their intended purpose, decisions concerning their derivation and use should be based on the biological, ecological, and toxicological characteristics of aquatic organisms and ecosystems and their uses whenever possible.
- It takes into account all excursions in the flow record.
- It provides the necessary design flow directly without requiring any design flow statistics in the xQy format.
- It is flexible enough so that any averaging period and frequency selected for particular pollutants, effluents, or site-specific criteria can be used directly in design flow calculations.

3.4 Example Cases

The sixty flow records that were analyzed using the hydrologically-based method (see Table 2-1) were also analyzed using the biologically-based design flow method. The CMC design flow was calculated for a 1-day averaging period and the CCC design flow was calculated using the 4-day averaging period. Both were calculated using a frequency of once every three years on the average. Table 3-1 presents biologically-based design flows for these sixty rivers.

In addition to the hydrologically-based design flows, Table B-1 in Appendix B also includes biologically-based CMC and CCC design flows for 13 streams for 30-day averaging periods and a frequency of once every three years on the average. The purpose of the biologically-based design flows for ammonia (5) in Appendix B is to illustrate how this method might be used for site-specific and pollutant-specific situations where the durations and frequencies in aquatic life criteria might be different from those specified in national two-number aquatic life criteria.

Analyses of the 1-day 3-year and the 4-day 3-year low flows in Table 3-1 indicate that the mean ratio of the 4-day 3-year low flows to the corresponding 1-day 3-year low flows is 1.23. The median of the ratios is 1.11, whereas the range of the ratios is 1.0 to 2.81. Thus, 4-day 3-year low flows are generally 11 to 23% greater than the corresponding 1-day 3-year low flows, although in one case, the 4-day 3-year low flow is 2.81 times greater than the corresponding 1-day 3-year low flow.

Table 3-1. Biologically-based design flows (ft^3/sec) for 60 rivers

Station ID	River name	State	Period of record	CV*	Design flows (ft^3/sec) 1-day 3-year	4-day 3-year	CCC/CMC
01657000	Bull Run	VA	1951-82	4.48	0.2	0.4	2.00
02092500	Trent	NC	1951-82	1.77	1.4	1.6	1.14
06026000	Birch Cr	MT	1946-77	1.32	1.7	2.4	1.41
12449600	Beaver Cr	WA	1960-78	1.77	2.8	3.4	1.21
05522000	Iroquois	IN	1949-78	1.33	2.4	3.0	1.25
09490800	N Fk White	AZ	1966-78	1.24	4.8	5.3	1.10
14372500	E Fk Illinois	OR	1942-83	2.03	5.8	6.9	1.19
05381000	Black	WI	1905-83	2.51	5.0	6.1	1.22
10291500	Buckeye	CA	1911-78	1.30	7.0	7.2	1.03
05585000	La Moine	IL	1921-83	1.99	8.9	9.4	1.06
12321500	Boundary Cr	ID	1928-84	1.65	12.0	13.0	1.08
01111500	Branch	RI	1940-82	1.16	10.0	13.2	1.32
02138500	Linville	NC	1922-84	1.74	13.0	15.0	1.15
05059000	Sheyenne	ND	1951-81	2.10	15.4	17.6	1.14
02083000	Fishing Cr	NC	1927-82	1.48	12.0	13.5	1.13
01196500	Quinnipiac	CT	1931-84	1.02	14.9	34.0	2.28
02133500	Drowning Cr	NC	1940-78	0.80	33.9	36.2	1.07
06280300	Shoshone	WY	1957-84	1.54	42.9	45.8	1.07
09149500	Uncompahgre	CO	1939-80	0.86	39.9	49.0	1.26
02296750	Peace	FL	1931-84	1.54	48.0	55.2	1.15
07018500	Big	MO	1922-84	2.16	45.0	51.5	1.14
02217500	Middle Oconee	GA	1902-84	1.37	33.0	45.7	1.38
01600000	N Br Potomac	MD	1939-83	1.42	42.9	49.0	1.17
09359500	Animas	CO	1946-56	1.56	60.0	61.1	1.02
01403060	Raritan	NJ	1904-83	1.64	46.9	53.6	1.14
01481000	Brandywine	PA	1912-84	1.17	55.8	59.3	1.06
09497500	Salt	AZ	1925-80	2.05	63.0	69.5	1.10
01144000	White	VT	1915-84	1.43	75.9	86.0	1.13
02413500	L Tallapoosa	AL	1940-51	1.33	57.9	70.2	1.21
01421000	E B Delaware	NY	1915-73	1.41	82.0	91.4	1.11
07288500	Big Sunflower	MS	1936-80	1.42	82.7	85.4	1.03
07013000	Meramec	MO	1923-78	2.41	89.9	92.7	1.03
01531000	Chemung	NY	1915-78	1.91	85.7	92.5	1.08
07096000	Arkansas	CO	1901-81	1.12	89.9	114.0	1.27
09070000	Eagle	CO	1947-80	1.36	120.0	126.0	1.05
01011000	Allegash	ME	1932-83	1.39	134.0	138.4	1.03
03528000	Clinch	TN	1919-78	1.55	127.7	132.2	1.04
13023000	Greys	WY	1937-83	1.16	124.8	135.8	1.09
02424000	Cahaba	AL	1902-78	2.07	122.8	149.8	1.22

Table 3-1 (Continued)

Station ID	River name	State	Period of record	CV*	Design flows (ft³/sec) 1-day 3-year	4-day 3-year	CCC/CMC
05515500	Kankakee	IN	1926-78	0.48	167.6	174.2	1.04
02490500	Bouge Chitto	MS	1945-81	1.89	187.5	189.6	1.01
01315500	Hudson	NY	1908-78	1.10	170.0	191.9	1.13
01610000	Potomac	WV	1939-83	1.48	202.2	219.6	1.09
05386000	Root	MN	1938-61	1.65	239.3	239.7	1.00
02369000	Shoal	FL	1939-82	0.95	270.5	286.0	1.06
07378500	Amite	LA	1939-83	1.98	282.1	295.5	1.05
06465500	Niobrara	NE	1939-83	0.59	199.7	304.3	1.52
02135000	Little Pee Dee	SC	1942-78	0.94	298.7	298.9	1.00
08110200	Brazos	TX	1966-78	1.48	277.7	305.3	1.10
02076000	Dan	VA	1924-52	1.25	321.6	380.4	1.18
03455000	French Broad	TN	1901-78	0.93	494.3	535.5	1.08
05333500	St. Croix	WI	1914-81	0.61	477.5	508.5	1.06
06287000	Bighorn	MT	1935-79	0.82	364.0	520.2	1.43
03107500	Beaver	PA	1957-83	1.10	539.9	557.5	1.07
13341000	N F Clearwater	ID	1927-68	1.16	469.6	613.0	1.31
07341500	Red	AR	1928-81	1.41	537.4	603.3	1.12
02350500	Flint	GA	1930-58	1.00	262.5	731.0	2.79
01100000	Merrimack	MA	1924-83	1.01	284.0	797.3	2.81
14233400	Cowlitz	WA	1968-78	0.93	934.7	959.9	1.03

*CV = Coefficient of Variation

For further clarification of the biologically-based method, refer to Appendix E, Questions and Answers.

SECTION 4. COMPARISON OF THE TWO METHODS

4.1 Design Flows

Table 4-1 shows how the biologically-based 1-day 3-year low flows and the hydrologically-based 1Q10 low flows for the sixty example rivers. The table also presents the difference between 4-day 3-year low flows and the 7Q10 low flows.

For 39 of the 60 streams, the 1-day 3-year low flows are less than the 1Q10 low flows. For 18 streams, the 1-day 3-year low flows are greater than the 1Q10 low flows, and for the remaining 3 streams the differences are less than 0.1%. Thus, for the majority of the streams the 1-day 3-year low flow is lower than the 1Q10 low flow. For all sixty streams, the difference between 1-day 3-year low flows and 1Q10 low flows ((1-day 3-year)-(1Q10))/(1-day 3-year) ranges from -50.0% to 20.8%, with the mean and median equal to -4.9% and -3.1%, respectively.

Table 4-1. Comparison of 1Q10 and 7Q10 with 1-day 3-yr and 4-day 3-yr low flows (all flows in ft^3/sec.)

		Comparison of CMC Design Flows			Comparison of CCC Design Flows		
River Name	State	1Q10	1-day 3-yr	%DIFF*	7Q10	4-day 3-yr	%DIFF**
Bull Run	VA	0.3	0.2	-50.0	0.4	0.4	0.0
Trent	NC	1.4	1.4	0.0	1.6	1.6	0.0
Birch Cr	MT	1.7	1.7	0.0	2.4	2.4	0.0
Beaver Cr	WA	2.4	2.8	14.3	3.2	3.4	5.9
Iroquois	IN	3.4	2.4	-41.7	3.9	3.0	-30.0
N Fk White	AZ	4.8	4.8	0.0	5.3	5.3	0.0
E Fk Illinois	OR	6.4	5.8	-10.3	6.7	6.9	2.9
Black	WI	5.5	5.0	-10.0	6.7	6.1	-9.8
Buckeye	CA	7.1	7.0	-1.4	7.7	7.2	-6.9
La Moine	IL	9.3	8.9	-4.5	9.9	9.4	-5.3
Boundary Cr	ID	11.7	12.0	2.5	13.1	13.0	-0.8
Branch	RI	8.8	10.0	12.0	13.3	13.2	-0.8
Linvillle	NC	13.4	13.0	-3.1	16.4	15.0	-9.3
Sheyenne	ND	15.9	15.4	-3.2	18.3	17.6	-4.0
Fishing Cr	NC	17.0	12.0	-41.7	19.4	13.5	-43.7
Quinnipiac	CT	17.5	14.9	-17.4	32.3	34.0	5.0
Drowning Cr	NC	38.8	33.9	-14.4	43.4	36.2	-19.9
Shoshone	WY	41.8	42.9	2.6	46.8	45.8	-2.2
Uncompahgre	CO	35.6	39.9	10.8	50.8	49.0	-3.7
Peace	FL	49.0	48.0	-2.1	55.3	55.2	-0.2
Big	MO	46.4	45.0	-3.1	55.3	51.5	-7.4
Middke Oconee	GA	49.4	33.0	-49.7	57.4	45.7	-25.6
N Br Potomac	MD	54.7	42.9	-27.5	61.6	49.0	-25.7
Animas	CO	54.8	60.0	8.7	62.3	61.1	-2.6
Raritan	NJ	54.2	46.9	-15.6	67.1	53.6	-25.2
Brandywine	PA	61.4	55.8	-10.0	67.2	59.3	-13.3
Salt	AZ	64.6	63.0	-2.5	68.7	69.5	1.2
White	VT	75.3	75.9	0.8	85.2	86.0	0.9
L Tallapoosa	AL	72.7	57.9	-25.6	88.3	70.2	-25.8
E B Delaware	NY	80.8	82.0	1.5	89.7	91.4	1.9
Big Sunflower	MS	89.4	82.7	-8.1	91.9	85.4	-7.6
Meramec	MO	88.8	89.9	1.2	92.2	92.7	0.5
Chemung	NY	89.7	85.7	-4.7	97.5	92.5	-5.4
Arkansas	CO	99.9	89.9	-11.1	120.1	114.0	-9.3
Eagle	CO	116.9	120.0	2.6	131.0	126.0	-4.0
Allegash	ME	124.5	134.0	7.1	134.1	138.4	3.1
Clinch	TN	128.7	127.7	-0.8	135.2	132.2	-2.3
Greys	WY	122.9	124.8	1.5	144.5	135.8	-6.4
Cahaba	AL	151.9	122.8	-23.7	156.4	149.8	-4.4

* %Difference = ((1-day 3-year flow) - (1Q10)) * 100 / (1-day 3-year flow)

**%Difference = ((4-day 3-year flow) - (7Q10)) * 100 / (4-day 3-year flow)

Table 4-1. (Continued)

River Name	State	Comparison of CMC Design Flows: 1Q10	1-day 3-yr	%DIFF*	Comparison of CCC Design Flows: 7Q10	4-day 3-yr	%DIFF**
Kankakee	IN	179.0	167.6	-6.8	184.3	174.2	-5.8
Bouge Chitto	MS	188.6	187.5	-0.6	191.6	189.6	-1.1
Hudson	NY	207.7	170.0	-22.2	211.0	191.9	-10.0
Potomac	WV	209.6	202.2	-3.7	220.7	219.6	-0.5
Root	MN	229.7	239.3	4.0	245.6	239.7	-2.5
Shoal	FL	280.1	270.5	-3.5	291.4	286.0	-1.9
Amite	LA	298.1	282.1	-5.7	303.4	295.5	-2.7
Niobrara	NE	160.9	199.7	19.4	322.0	304.3	-5.8
Little Pee Dee	SC	306.7	298.7	-2.7	322.4	298.9	-7.9
Brazos	TX	311.6	277.7	-12.2	344.9	305.3	-13.0
Dan	VA	329.6	321.6	-2.5	387.3	380.4	-1.8
French Broad	TN	473.6	494.3	4.2	532.2	535.5	0.6
St. Croix	WI	505.9	477.5	-5.9	536.0	508.5	-5.4
Bighorn	MT	327.1	364.0	10.1	557.0	520.2	-7.1
Beaver	PA	571.3	539.9	-5.8	594.2	557.5	-6.6
N F Clearwater	ID	529.2	469.6	-12.7	648.6	613.0	-5.8
Red	AR	691.0	537.4	-28.6	769.2	603.3	-27.5
Flint	GA	207.8	262.5	20.8	799.8	731.0	-9.4
Merrimack	MA	270.2	284.0	3.6	929.3	797.3	-16.6
Cowlitz	WA	901.5	934.7	4.9	968.7	959.9	-0.9

* %Difference = ((1-day 3-year flow) - (1Q10)) * 100 / (1-day 3-year flow)

**%Difference = ((4-day 3-year flow) - (7Q10)) * 100 / (4-day 3-year flow)

Similar comparisons can be made between the 4-day 3-year low flows and the 7Q10 low flows based on Table 4-1. For 46 of the 60 streams, the 4-day 3-year low flows are less than the 7Q10 low flows. For nine streams, 4-day 3-year low flows are greater than the 7Q10 low flows, and for the remaining four streams, the differences are less than 0.1%. Thus, the 4-day 3-year low flow is usually lower than the 7Q10 low flow. For all sixty streams, the difference between the 4-day 3-year low flows and 7Q10 low flows ((4-day 3-year) - (7Q10))/(4-day 3-year) ranges from -44% to 6%, with the mean and median equal to - 7.0% and - 4.4%, respectively.

4.2 Excursions

Table 4-2 presents the calculated number of excursions that occurred in the 60 streams for the low flows calculated using the hydrologically- and biologically-based methods. The table demonstrates the impact of the choice of one design flow method over the other in terms of number of excursions. For any stream, a higher flow will always result in the same or a greater number of excursions than a lower flow. Occasionally, the difference in the number of excursions of the two design flows is quite dramatic even if the difference between the two design flows is quite small. For example, the 1Q10 and the 1-day 3-year design flow of the Quinnipiac River in Connecticut are 17.5 ft^3/sec and 14.9 ft^3/sec, respectively, but the corresponding number of excursions were 39 and 13. Similar observations could be made for many other streams in Table 4-2. A small difference in design flow may not have a significant impact in wasteload allocations for these streams but may result in a larger number of excursions than desired during the period of flow record.

4.3 Comparison of the Two Methods

The comparisons of the design flows show that the magnitudes of the 1-day 3-year and 1Q10 low flows, and the 4-day 3-year and 7Q10 low flows are, on an average basis, similar in magnitude. Although these flows are similar on the average, there may be large differences in the values of these flows for individual streams. More importantly, there can be a significant difference in the number of excursions that result, even if the magnitudes of the flows calculated by the two methods are nearly equal.

Table 4-2. Comparison of number of excursions of 1Q10 and 7Q10 with number of excursions of 1-day 3-yr and 4-day 3-yr design flows.

River Name	State	Comparison of CMC Design Flows				Comparison of CCC Design Flows			
		1Q10	#Excur	1-day 3-yr	#Excur	7Q10	#Excur	4-day 3-yr	#Excur
Bull Run	VA	0.3	19	0.2	10	0.4	8.50	0.4	8.5
Trent	NC	1.4	9	1.4	9	1.6	9.25	1.6	9.2
Birch Cr	MT	1.7	8	1.7	8	2.4	9.25	2.4	9.2
Beaver Cr	WA	2.4	1	2.8	6	3.2	4.00	3.4	6.0
Iroquois	IN	3.4	18	2.4	9	3.9	16.75	3.0	9.7
N Fk White	AZ	4.8	2	4.8	2	5.3	4.00	5.3	4.0
E Fk Illinois	OR	6.4	13	5.8	12	6.7	11.25	6.9	11.5
Black	WI	5.5	27	5.0	21	6.7	26.00	6.1	24.5
Buckeye	CA	7.1	13	7.0	7	7.7	10.00	7.2	8.5
La Moine	IL	9.3	33	8.9	20	9.9	24.50	9.4	20.5
Boundary Cr	ID	11.7	15	12.0	15	13.1	15.75	13.0	15.7
Branch	RI	8.8	10	10.0	13	13.3	18.25	13.2	14.0
Linville	NC	13.4	21	13.0	15	16.4	25.00	15.0	[illegible]
Sheyenne	ND	15.9	11	15.4	6	18.3	14.50	17.6	[illegible]
Fishing Cr	NC	17.0	17	12.0	15	19.4	29.25	13.5	[illegible]
Quinnipiac	CT	17.5	39	14.9	13	32.3	11.25	34.0	13.0
Drowning Cr	NC	38.8	26	33.9	12	43.4	27.75	36.2	12.7
Shoshone	WY	41.8	3	42.9	6	46.8	9.25	45.8	[illegible]
Uncompahgre	CO	35.6	7	39.9	13	50.8	17.50	49.0	[illegible]
Peace	FL	49.0	17	48.0	16	55.3	17.25	55.2	[illegible]
Big	MO	46.4	23	45.0	15	55.3	27.75	51.5	3.25
Middle Oconee	GA	49.4	25	33.0	11	57.4	23.25	45.7	[illegible]
N Br Potomac	MD	54.7	29	42.9	14	61.6	28.00	49.0	14.75
Animas	CO	54.8	0	60.0	2	62.3	6.75	61.1	2.5
Raritan	NJ	54.2	25	46.9	13	67.1	24.25	53.6	13.25
Brandywine	PA	61.4	30	55.8	14	67.2	33.00	59.3	18.0
Salt	AZ	64.6	21	63.0	18	68.7	17.25	69.5	18.0
White	VT	75.3	20	75.9	20	85.2	20.75	86.0	21.5
L Tallapoosa	AL	72.7	6	57.9	3	88.3	7.00	70.2	3.75
E B Delaware	NY	80.8	17	82.0	20	89.7	19.00	91.4	20.50
Big Sunflower	MS	89.4	31	82.7	8	91.9	30.25	85.4	13.75
Meramec	MO	88.8	17	89.9	18	92.2	16.50	92.7	17.00
Chemung	NY	89.7	26	85.7	18	97.5	25.00	92.5	20.50

Table 4-2. (Continued)

River Name	State	Comparison of CMC Design Flows				Comparison of CCC Design Flo[illegible]			
		1Q10	#Excur	1-day 3-yr	#Excur	7Q10	#Excur	4-day 3-yr	#Exc.
Arkansas	CO	107.9	23	115.8	26	126.1	28.00	123.8	25.[illegible]
Eagle	CO	116.9	9	120.0	11	131.0	17.50	126.0	11.[illegible]
Allegash	ME	124.5	15	134.0	17	134.1	13.00	138.4	7.[illegible]
Clinch	TN	128.7	23	127.7	17	135.2	25.00	132.2	13.[illegible]
Greys	WY	122.9	10	124.8	10	144.5	18.75	135.8	10.[illegible]
Cahaba	AL	151.9	33	122.8	10	156.4	24.75	149.8	16.[illegible]
Kankakee	IN	179.0	34	167.6	14	184.3	29.50	174.2	14.[illegible]
Bogue Chitto	MS	188.6	13	187.5	10	191.6	19.25	189.6	11.[illegible]
Hudson	NY	207.7	30	170.0	29	211.0	27.75	191.9	24.[illegible]
Potomac	WV	209.6	19	202.2	14	220.7	15.00	219.6	14.[illegible]
Root	MN	229.7	7	239.3	7	245.6	10.75	239.7	7.[illegible]
Shoal	FL	280.1	20	270.5	12	291.4	19.25	286.0	17.[illegible]
Amite	LA	298.1	19	282.1	14	303.4	14.00	295.5	4.[illegible]
Niobrara	NE	160.9	4	199.7	8	322.0	11.25	304.3	8.[illegible]
Little Pee Dee	SC	306.7	15	299.7	12	322.4	15.00	298.9	[illegible]
Brazos	TX	311.6	11	277.7	4	344.9	6.75	305.3	[illegible]
Dan	VA	329.6	11	321.6	9	387.3	10.25	380.4	[illegible]
French Broad	TN	473.6	13	494.3	18	532.2	16.00	535.5	[illegible]
St. Croix	WI	505.9	34	477.5	22	536.0	34.50	508.5	[illegible]
Bighorn	MT	327.1	12	364.0	14	557.0	16.50	520.2	[illegible]
Beaver	PA	571.3	15	539.9	4	594.2	13.25	557.5	[illegible]
N F Clearwater	ID	529.2	20	469.6	13	643.6	14.75	613.0	[illegible]
Red	AR	691.0	28	537.4	17	769.2	28.75	603.3	[illegible]
Flint	GA	207.8	7	262.5	9	799.8	20.25	731.0	8.[illegible]
Merrimack	MA	270.2	13	284.0	18	929.3	41.75	797.3	19.[illegible]
Cowlitz	WA	901.5	0	934.7	2	963.7	4.50	959.9	3.[illegible]

The hydrologically-based design flows may actually provide a greater degree of protection of water quality in cases where the value of the design flows are less than that of the corresponding biologically-based design flows. Hydrologically-based design flows have been used successfully in the past in many water quality-based permits. In addition, on an average basis, the values of hydrologically-based design flows are not greatly different from the corresponding values of biologically-based design flows.

The biologically-based design flows are not always smaller than the corresponding hydrologically-based design flows for a given stream. Thus, it cannot be stated that choosing one method over the other will always result in the most protective wasteload allocation (and therefore the fewest number of excursions over the period of record). However, the biologically-based method will always provide insurance that the design flow calculated will have resulted in no more than the required number of excursions.

Based upon the above, both the hydrologically-based and the biologically-based methods for calculating stream design flows are recommended for use in steady-state modeling.

SECTION 5. RECOMMENDATIONS

1. If steady-state modeling is used, the hydrologically-based or the biologically-based stream design flow method should be used. If the hydrologically-based method is used, the 1Q10 and 7Q10 low flows should be used as the CMC and CCC design flows, except that the 30Q10 low flow should be used as the CCC design flow for ammonia in situations involving POTW's designed to remove ammonia where limited variability of effluent pollutant concentrations and resulting concentrations in the receiving water can be demonstrated.

2. Other technically defensible methods may also be used.

SECTION 6. REFERENCES

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APPENDIX A. Calculation of Hydrologically-based Design Flows

Design flows can be calculated as annual x-day average low flows whose return period is y years, i.e., the xQy low flow. These flows can be estimated from a historical flow record of n years using two different methods. The first is a distribution-free method which makes no assumption about the true probability distribution of annual low flows. The expression for xQy is

$$xQy = (1-e)\,X(m1) + eX(m2)$$

where X(m) = the m-th lowest annual low flow of record
m1 = [(n+1)/y]
m2 = [(n+1)/y] + 1
[z] = the largest integer less than or equal to z
e = (n+1)/y - [(n+1)/y]

This method is only appropriate when the desired return period is less than n/5 years (1).

The second method fits the historical low flow data to a specific probability density function and then computes from this function the flow whose probability of not being exceeded is 1/y. The log Pearson Type III distribution is a convenient function to use because it can accommodate a large variety of distributional shapes and has seen wide-spread use in streamflow frequency analysis. However, there is no physically based rationale for choosing one distribution over another.

The xQy low flow based on the log Pearson Type III method is

$$xQy = \exp(u + K(g,y)\,s)$$

where u = mean of the logarithms (base e) of the historical annual low flows,
s = standard deviation of the logarithms of the historical low flows,
g = skewness coefficient of the logarithms of the historical low flows,
K = frequency factor for skewness g and return period y.

A sample listing of frequency factors is given in Table A-1. These factors can also be approximated as

$$K = (2/g)[(1 + (g\,z)/6 - g^2/36)^3 - 1]$$

for $|g| \leq 3$ where z is the standard normal variate with cumulative probability 1/y (2). Tables of the normal variates are available in most elementary statistics texts. An approximate value (3) can be found from

$$z = 4.91\,[(1/y)^{.14} - (1-1/y)^{.14}].$$

To illustrate the use of the two xQy low flow estimation methods, the data in Table A-2 will be analyzed for the 7Q5. The flow values in this table represent the lowest 7-day average flow for each year of record. Also shown are the rankings of these flows from lowest (rank 1) to highest (rank 45). The mean, standard deviation, and skewness coefficient of the logarithms of these annual low flows are shown at the bottom of the table.

For the distribution-free approach, the value of (n+1)/y is (45+1)/5 or 9.2. Therefore, the 7Q5 low flow lies between the 9-th and 10-th lowest annual flow. The interpolation factor, e, is 9.2 - 9 = 0.2. Thus we have

$$\begin{aligned} 7Q5 &= (1. - .20)\,X(9) + (.20)\,X(10) \\ &= (.80(335) + (.20)(338) \\ &= 335.6 \text{ cfs} \end{aligned}$$

For the log Pearson Type III method, the frequency factor K will be estimated from Table A-1. For skewness of 0.409 and a 5-year return period interpolation results in K = -0.856. The 7Q5 low flow is

$$7Q5 = \exp(6.01 + (-.856)(.24))$$
$$= 331.8 \text{ cfs}$$

For purposes of comparison, K will be estimated using the formulae given above:

$$z = 4.91 [(0.2)^{.14} - (1-0.2)^{.14}]$$
$$= -0.840$$

$$K = (2/.409)[(1 + (.409)(-.840)/6 - (.409)/36)^3 - 1]$$
$$= -.853$$

$$7Q5 = \exp(6.01 + (-.853)(.24))$$
$$= 331.8 \text{ cfs}$$

The difference in the three estimates of the 7Q5 low flow is less than 2 percent.

Table A-1. Frequency Factors (K) for the log Pearson Type III Distribution

Skewness Coefficient	Return Period, Years 5	10
3.0	-0.636	-0.660
2.8	-0.666	-0.702
2.6	-0.696	-0.747
2.4	-0.725	-0.795
2.2	-0.752	-0.844
2.0	-0.777	-0.895
1.8	-0.799	-0.945
1.6	-0.817	-0.994
1.4	-0.832	-1.041
1.2	-0.844	-1.086
1.0	-0.852	-1.128
0.8	-0.856	-1.166
0.6	-0.857	-1.200
0.4	-0.855	-1.231
0.2	-0.850	-1.258
0.0	-0.842	-1.282
-0.2	-0.830	-1.301
-0.4	-0.816	-1.317
-0.6	-0.800	-1.328
-0.8	-0.780	-1.336
-1.0	-0.758	-1.340
-1.2	-0.732	-1.340
-1.4	-0.705	-1.337
-1.6	-0.675	-1.329
-1.8	-0.643	-1.318
-2.0	-0.609	-1.302
-2.2	-0.574	-1.284
-2.4	-0.537	-1.262
-2.6	-0.499	-1.238
-2.8	-0.460	-1.210
-3.0	-0.420	-1.180

Table A-2. Annual 7-Day Low Flows (ft^3/sec) for the Amite River Near Denham Springs, LA

Year	Flow	Rank	Year	Flow	Rank
1939	299	5	1962	396	25
1940	338	10	1963	275	1
1941	355	15	1964	392	24
1942	439	30	1965	348	11
1943	371	20	1966	385	22
1944	410	28	1967	335	9
1945	407	27	1968	306	6
1946	508	38	1969	280	3
1947	450	33	1970	354	14
1948	424	29	1971	388	23
1949	574	41	1972	357	17
1950	489	36	1973	499	37
1951	406	26	1974	448	32
1952	291	4	1975	650	45
1953	352	13	1976	356	16
1954	309	7	1977	364	18
1955	322	8	1978	648	44
1956	278	2	1979	619	43
1957	369	19	1980	567	40
1958	483	35	1981	445	31
1959	523	39	1982	349	12
1960	385	21	1983	595	42
1961	474	34			

$n = 45$
$u = 6.0$
$s = 0.23$
$g = 0.385$

REFERENCES

1. Linsley, R.K., et al., Hydrology for Engineers, 2nd Edition, McGraw-Hill, New York, NY, 1977.

2. Loucks, D.P., et al., Water Resource Systems Planning and Analysis, Prentice-Hall, Englewood Cliffs, NJ, 1981.

3. Joiner and Rosenblatt, JASA, 66:394, 1971.

APPENDIX B. An Example Use Of DFLOW For Ammonia Discharges From POTWs

The purpose of this Appendix is to illustrate the use of the DFLOW program to calculate biologically-based design flows for ammonia and compare them with the hydrologically-based design flows of 30Q10 for the 13 streams with the lowest coefficients of variation shown in Table 2-1.

B.1 Introduction

As stated in the two-number WQC for ammonia (1), a CCC averaging period of as long as 30 days may be used in situations involving POTWs designed to remove ammonia where low variability of effluent pollutant concentration and resultant concentrations in receiving waters can be demonstrated. In cases where low variability can be demonstrated, longer averaging periods for the ammonia CCC (e.g., a 30-day averaging period) would be acceptable because the magnitudes and durations of excursions above the CCC would be sufficiently limited (1).

B.2 Hydrologically-based Design Flow

The 30Q10 low flows of the 13 streams with the lowest coefficients of variation (CV) are presented in Table B-1.

Table B-1. Design flows and resulting number of excursions using a 30-day averaging period (all flows in ft^3/sec).

River Name	State	Coeff of Variation	30Q10 Flow	30Q10 # Excursions	30-day 3-year Flow	30-day 3-year # Excursions	*% Diff
Quinnipiac	CT	1.02	42.3	7.8	46.5	15.0	9.0
Drowning Cr	NC	0.80	54.7	8.5	65.5	15.0	16.5
Uncompahgre	CO	0.86	71.0	6.9	77.3	14.6	8.2
Greys	WY	1.16	160.7	5.7	166.9	9.9	3.7
Kankakee	IN	0.48	201.8	10.0	213.6	16.7	5.5
Hudson	NY	1.10	298.0	13.4	340.7	24.3	12.5
Shoal	FL	0.95	323.5	10.2	339.0	12.1	4.6
Little Pee Dee	SC	0.94	366.3	7.4	450.0	11.8	18.6
St. Croix	WI	0.61	571.8	16.2	598.6	21.9	4.5
Niobrara	NE	0.59	613.2	6.4	673.6	8.1	9.0
French Broad	TN	0.93	636.2	11.9	715.7	20.3	11.1
Bighorn	MT	0.82	913.6	8.1	1103.0	14.3	17.2
Flint	GA	1.00	1000.0	6.4	1097.0	9.6	8.8

*%Difference = ((30-day 3-year flow) - (30Q10)) * 100 / (30-day 3-year flow)

B.3 Biologically-based Design Flow

The 30-day 3-year low flows for 13 streams are presented in Table B-1. To obtain the biologically-based design flow for these streams, an averaging period of 30 days instead of 4 days was entered into the DFLOW program (see Table D-3, page D-6). Table B-1 also includes the number of excursions that occurred in each of 13 flow records for the hydrologically and biologically-based design flows.

B.4 Comparison of Design Flows

Table B-1 shows that for all 13 streams the 30Q10 low flow is always less than the 30-day 3-year low flow. The difference between the low flows ((30-day 3-year - 30Q10)/ 30-day 3-year)) 3.7% to 18.6% with the mean equal to 10.2%. Because the 30Q10 low flow is always lower, it results in fewer excursions than the 30-day 3-year low flow.

B.5 Use of Biologically-Based Design Flows for Ammonia Discharges from POTWs

As stated earlier, an averaging period of 4 days and a frequency of occurrence of once every three years is used for the CCC. However, for ammonia discharges from POTWs, a longer averaging period may be used in certain cases. According to the national WQC for ammonia, an averaging period as long as 30 days may be used in situations involving POTWs designed to remove ammonia where low variability of effluent concentrations and the resulting concentrations in the receiving waters can be demonstrated. In cases where low variability can be demonstrated, longer averaging periods for the ammonia CCC (e.g., a 30-day averaging period) would be acceptable because the magnitudes and durations of excursions above the CCC would be sufficiently limited.

In Section 4.1, the hydrologically-based design flows have been compared with the biologically-based design flows for the 4-day averaging period for all pollutants. Appendix B shows a comparison between the biologically-based 30-day 3-year low flows and the hydrologically-based 30Q10 low flows for 13 streams for ammonia. For these 13 streams, the 30Q10 flow was always less than the 30-day 3-year flow, by an average of 10.2%. Thus, the use of the 30Q10 as the design flow is relatively more protective for these streams

REFERENCE

1. U.S. EPA. 1985d. Ambient water quality criteria for ammonia - 1984. EPA 440/5-85-001. National Technical Information Service, Springfield, VA.

APPENDIX C. Calculation of a Biologically-based Design Flows

The biologically-based design flow calculation method is an iterative convergence procedure consisting of five parts. In Part I, Z (the allowed number of excursions) is calculated. In Part II, the set of X-day running averages is calculated from the record of daily flows. Because the ambient (instream) concentration of a pollutant can be considered to be inversely proportional to stream flow, the appropriate "running averages" of stream flow are actually "running harmonic means." (The harmonic mean of a set of numbers is the reciprocal of the arithmetic mean of the reciprocals of the numbers.) Thus, "X-day running averages" should be calculated as $X/\Sigma(1/F)$, not as $(\Sigma F)/X$, where F is the flow for an individual day. Throughout this Appendix C, the term "running average" will mean "running harmonic mean."

Part III describes the calculation of N (the total number of excursions of a specified flow in the flow record). The calculations described in Part III will be performed for a number of different flows that are specified in Parts IV and V. In Part IV, initial lower and upper limits on the design flow are calculated, the number of excursions at each limit are calculated using Part III, and an initial trial flow is calculated by interpolation between the lower and upper limits. In Part V, successive iterations are performed using the method of false position (1) to calculate the design flow as the highest flow that results in no more than the number of allowed excursions calculated in Part I.

Part I. Calculation of allowed number of excursions.

I-1. Calculate Z = D/[(Y)(365.25 days/year)] where D = the number of days in the flow record;

Y = the average number of years specified in the frequency; and

Z = the allowed number of excursions.

Part II. Calculation of X-day running averages, i.e., x-day running harmonic means.

II-1. Where X = the specified duration (in days) of the averaging period, calculate the set of X-day running averages for the entire flow record, i.e., calculate an X-day average starting with day 1, day 2, day 3, etc. Each average will have X-1 days in common with the next average, and the number of X-day averages calculated from the flow record will be (D+1-X).

Part III. Determination of the number of excursions of a specified flow in a set of running averages, i.e., running harmonic means.

III-1. Obtain a specified flow of interest from either Part IV or Part V.

III-2. In the set of X-day running averages for the entire flow record, record the date for which the first average is below the specified flow and record the number of consecutive days that are part of at least one or more of the X-day averages that are below the specified flow. (Note that whether a day is counted as an excursion day does not depend exclusively on whether the X-day average for that day is below the specified flow of interest. Instead, it depends entirely on whether that day is part of any X-day average that is below the specified flow. Table C-1 provides examples of the counting of excursion days.)

Table C-1. Counting excursion days for a specified flow of 100 ft^3/sec using 4-day averages

Date	Daily flow	4-day avg flow	Is the 4-day average below 100?	Is this date part of any 4-day average that is below 100?	Date of start of excursion period	Number of days in excursion period	Date of start of low flow period	Number of excursion days in low flow period	Number of excursions in low flow period
1	130	112.5	No	No					
2	120	102.5	No	No					
3	110	97.5	Yes	Yes	3	4	3	12	3
4	90	102.5	No	Yes					
5	90	117.5	No	Yes					
6	100	112.5	No	Yes					
7	130	102.5	No	No					
8	150	102.5	No	No					
9	70	87.5	Yes	Yes	9	8			
10	60	90.0	Yes	Yes					
11	130	102.5	No	Yes					
12	90	95.0	Yes	Yes					
13	80	97.5	Yes	Yes					
14	110	127.5	No	Yes					
15	100	225.0	No	Yes					
16	100	>100	No	Yes					
17	200	>100	No	No					
18	500	>100	No	No					

The daily flows and four-day average flows for days 19 to 200 are all above 100 ft^3/sec

Thus the starting date and the duration (in days) of the first excursion period will be recorded. By definition, the minimum duration is X days.

III-3. Determine the starting dates of, and number of days in, each succeeding excursion period in the flow record.

III-4. Identify all of the excursion periods that begin within 120 days after the beginning of the first excursion period. (Although the first excursion period is often the only one in the 120-day period, two or three sometimes occur within the 120 days. Rarely do any excursion periods occur during days 121 to 240.) All of these excursion periods are considered to be in the first low flow period. Add up the total number of excursion days in the first low flow period and divide the sum by X to obtain the number of excursions in the first low flow period. If the number of excursions is calculated to be greater than 5.0, set it equal to 5.0

III-5. Identify the first excursion period that begins after the end of the first low flow period, and start the beginning of the second 120-day low flow period on the first day of this excursion period. Determine the number of excursion days and excursions in the second low flow period.

III-6. Determine the starting dates of, and the number of excursions in, each succeeding 120-day low flow period.

III-7. Sum the number of excursions in all the low-flow periods to determine S = the total number of excursions of the specified flow of interest.

Part IV. Calculation of initial limits of the design flow and initial trial flow.

IV-1. Use L = 0 as the initial lower limit.

IV-2. Use U = the XQY low flow as the initial upper limit.

IV-3. Use N_L=0 as the number of excursions (see Part III) of the initial lower limit.

IV-4. Calculate N_U = the number of excursions (See Part III) of the initial upper limit.

IV-5. Calculate T = the initial trial flow as $T = L + \frac{(Z-N_L)(U-L)}{(N_U-N_L)}$

Part V. Iterative convergence to the design flow.

V-1. Calculate N_T = the number of excursions (see Part III) of the trial flow.

V-2. If $-0.005 \leq ((N_T-Z)/Z) \leq +0.005$, use T as the design flow and stop.

If $N_T > Z$, set U = T and $N_U = N_T$.

If $N_T < Z$, set L = T and $N_L = N_T$.

V-3. If $((U-L)/U) \leq 0.005$, use L as the design flow and stop.

Otherwise, calculate a new trial flow as $T = L + \frac{(Z-N_L)(U-L)}{(N_U-N_L)}$ and repeat steps V-1, V-2, and V-3 as necessary.

REFERENCE

1. Carnahan, B., H.A. Luther, and J.O. Wilkes. 1969. Applied numerical methods. Wiley, New York.

APPENDIX D. Description of the DFLOW Computer Program

DFLOW is a computer program that can perform a variety of calculations related to design flow for any stream for which daily flow data are in STORET. The program is installed on the U.S. EPA's NCC-IBM computer and is run under the TSO operating environment. DFLOW consists of two procedures: the first retrieves the daily flow record for the U.S. Geological Survey (USGS) gaging station of interest from the U.S. EPA's STORET system, whereas the second allows selection of one or more calculations.

After logging on to TSO, the user invokes the program by entering the command: exec 'mrfursc.dflow.clist'.

The following menu will appear:

```
ENTER THE NUMBER OF THE PROCEDURE YOU WISH TO EXECUTE:
1 RETRIEVE FLOW DATA FROM STORET
2 PERFORM CALCULATIONS USING RETRIEVED FLOW DATA
3 EXIT THE PROGRAM
```

If procedure 1 is selected, the user will be asked for the 8-digit USGS station number for the flow gage of interest and a 2-digit state code (see Table D-1). Gaging station numbers can be obtained from local USGS offices or through a separate retrieval from the STORET system. After this information is entered, a batch job is automatically submitted to the IBM system to carry out the STORET retrieval. The user may log off the system at this point because the retrieval might take several hours. An example flow retrieval session is shown in Table D-2.

After a period of time, the user can invoke the DFLOW program again and select procedure 2. If the flow data have not been successfully retrieved, the message "FILE NOT AVAILABLE" will appear. If the retrieval is not successful within about six hours, a new retrieval can be attempted. After a successful retrieval, procedure 2 will allow one or more of the following to be calculated:

1. A biologically-based CMC design flow using a 1-day averaging period and a frequency of allowed excursions of once every three years on the average. After the CMC design flow has been calculated and the excursion table printed for that flow, any flows can be entered in order to obtain CMC excursion tables for those flows.

2. A biologically-based CCC design flow using a 4-day averaging period and a frequency of allowed excursions of once every three years on the average. After the CCC design flow has been calculated and the excursion table printed for that flow, any flows can be entered in order to obtain CCC excursion tables for those flows.

3. One or more user-defined design flows. If a biologically-based design flow is selected, the user will be asked to input six variables so that the desired design flow and excursion table can be printed. If a hydrologically-based design flow is selected, the user will be asked to input four variables so that the desired xQy low flow can be calculated.

Table D-3 demonstrates the use of DFLOW for the Amite River in Louisiana. The allowed number of excursions and the CCC design flow are calculated, and the excursion table is printed. DFLOW is then used to calculate the 30-day 3-year biologically-based user-defined design flow. Finally, procedure 2 is used to calculate the 7Q10 low flow for the Amite River.

A copy of the FORTRAN source code for DFLOW can be obtained from Lewis A. Rossman, WERL, U.S. EPA, 26 West St. Clair Street, Cincinnati, OH 45268 (Telephone 513-684-7603 or FTS - 684-7603).

Table D-1. STORET State Codes

01	Alabama
02	Alaska
04	Arizona
05	Arkansas
06	California
08	Colorado
09	Connecticut
10	Delaware
11	Distr ct of Columbia
12	Florida
13	Georgia
15	Hawaii
16	Idaho
17	Illinois
18	Indiana
19	Iowa
20	Kansas
21	Kentucky
22	Louisiana
23	Maine
24	Maryland
25	Massachusetts
26	Michigan
27	Minnesota
28	Mississippi
29	Missouri
30	Montana
31	Nebraska
32	Nevada
33	New Hampshire
34	New Jersey
35	New Mexico
36	New York
37	North Carolina
38	North Dakota
39	Ohio
40	Oklahoma
41	Oregon
42	Pennsylvania
44	Rhode Island
45	South Carolina
46	South Dakota
47	Tennessee
48	Texas
49	Utah
50	Vermont
51	Virginia
53	Washington
54	West Virginia
55	Wisconsin
56	Wyoming

Table D-2. Example Flow Data Retrieval Using DFLOW (User input is underlined)

```
exec .'mrfu-er.dflow.clist'

ENTER THE NUMBER OF THE PROCEDURE YOU WISH TO E[illegible]E:
1  RETRIEVE FLOW DATA FROM STORET
2  PERFORM CALCULATIONS USING RETRIEVED FLOW DATA
3  EXIT THE PROGRAM
1

ENTER 8-DIGIT USGS STATION NUMBER .... 07378500
ENTER 2-DIGIT STORET STATE CODE ...... 22
SAVED
JOB ABC(JOB12345) SUBMITTED
AFTER JOB IS COMPLETED, FLOW DATA WILL RESIDE IN FILE DFLOW.DATA
```

Table D-3. Use of DFLOW for the Amite River.

```
$RUN  DFLOW.DFLOW.CLIST

ENTER THE NUMBER OF THE PROCEDURE YOU WISH TO EXECUTE:
1 RETRIEVE FLOW DATA FROM STORET
2 PERFORM CALCULATIONS USING RETRIEVED FLOW DATA
3 EXIT THE PROGRAM
2


BIOLOGICALLY BASED DESIGN FLOW FOR AMITE RIVER NEAR DENHAM SPRINGS, LA

ENTER THE NUMBER OF THE DESIGN FLOW YOU WISH TO CALCULATE:
1 - CMC,  2 - CCC,  3 - USER DEFINED,  4 - EXIT
?
2

CCC DESIGN FLOW FOR USGS STATION 07378500
------------------------------------------------------------
AMITE RIVER NEAR DENHAM SPRINGS, LA
PERIOD OF RECORD                      : 1939 TO 1988
ALLOWED NUMBER OF EXCURSIONS          :    16.17

DESIGN FLOW                           :   298.44 CFS
--------------------------------------------------------------
:      LOW FLOW PERIOD      :          EXCURSION PERIODS        :
--------------------------------------------------------------
:                NUMBER OF :                 DURATION  AVERAGE % :
: START DATE    EXCURSIONS   START DATE      (DAYS)   EXCURSION * :
..............................................................
: OCT 30, 1952     1.50   : OCT 30, 1952      6          1.7     :
--------------------------------------------------------------
: OCT 10, 1956     5.00   : OCT 10, 1956     30          4.3     :
--------------------------------------------------------------
: OCT 16, 1963     5.00     OCT 16, 1963     30          5.0     :
:                           NOV 11, 1963     10          5.2     :
--------------------------------------------------------------
: SEP 27, 1969     2.50     SEP 27, 1969     10          4.3     :
--------------------------------------------------------------
:    TOTAL        16.00   :                                      :
--------------------------------------------------------------
* % BY WHICH CRITERION CONCENTRATION IS EXCEEDED DURING AN EXCURSION

ENTER A FLOW (CFS) FOR WHICH YOU WANT AN EXCURSION TABLE OR 0 TO EXIT
?
0

ENTER THE NUMBER OF THE DESIGN FLOW YOU WISH TO CALCULATE:
1 - CMC,  2 - CCC,  3 - USER DEFINED,  4 - EXIT
?
3

ENTER THE NUMBER OF THE TYPE OF DESIGN FLOW YOU WISH TO DEFINE:
1 - BIOLOGICALLY BASED, 2 - EXTREME VALUE APP
?
1

ENTER VALUES FOR THE FOLLOWING (EXAMPLE VALUES ARE IN PARENTHESES):
NUMBER OF DAYS IN A FLOW AVERAGING PERIOD (1 FOR CMC, 4 FOR CCC)
?
30
```

Table D - 3. (Continued)

```
AVERAGE NUMBER OF YEARS BETWEEN EXCURSIONS (3)
?
3
MAXIMUM NUMBER OF EXCURSIONS IN A LOW-FLOW PERIOD (5)
?
5
MAXIMUM NUMBER OF DAYS IN A LOW FLOW PERIOD (120)
?
120
BEGINNING YEAR OF FLOW RECORD (1900)
?
1900
ENDING YEAR OF FLOW RECORD (1999)
?
1999

USER DEFINED DESIGN FLOW FOR USGS STATION [illegible]
---------------------------------------------------------------
WHITE RIVER NEAR [illegible] SPRINGS, LA.
PERIOD OF RECORD                      : 1939 TO 1988
ALLOWED NUMBER OF EXCURSIONS          :    16.17

DESIGN FLOW                           :   [illegible] CFS
```

: LOW FLOW PERIOD		: EXCURSION PERIODS		
START DATE	NUMBER OF EXCURSIONS	START DATE	DURATION (DAYS)	AVERAGE % EXCURSION *
SEP 23, 1939	3.13	SEP 23, 1939	96	5.9
SEP 10, 1952	3.40	SEP 10, 1952	73	7.8
SEP 9, 1956	2.99 *	SEP 9, 1956	89	9.2
SEP 9, 1963	3.17	SEP 9, 1963	95	6.8
OCT 7, 1968	1.30	OCT 7, 1968	36	3.3
TOTAL	12.[illegible]			

```
* % BY WHICH CRITERION CONCENTRATION IS EXCEEDED DURING AN EXCURSION.

ENTER A FLOW (CFS) FOR WHICH YOU WANT AN EXCURSION TABLE OR 0 TO QUIT
?
0

ENTER THE NUMBER OF THE DESIGN FLOW YOU WISH TO CALCULATE:
1 - CMC,  2 - CCC,  3 - USER DEFINED,  4 - EXIT
?
3

ENTER THE NUMBER OF THE TYPE OF DESIGN FLOW YOU WISH TO DEFINE:
1 - BIOLOGICALLY BASED, 2 - EXTREME VALUE [illegible]
?
2

ENTER VALUES FOR THE FOLLOWING (EXAMPLE VALUES ARE IN PARENTHESES):
FLOW AVERAGING PERIOD, DAYS (7)
?


?
RETURN PERIOD ON YEARS WITH EXCURSIONS, [illegible]
?
10
BEGINNING YEAR OF FLOW RECORD (1900)
?
1900
ENDING YEAR OF FLOW RECORD (1999)
?
1999

USER DEFINED DESIGN FLOW FOR USGS STATION [illegible]
---------------------------------------------------------------
WHITE RIVER NEAR [illegible] SPRINGS, LA.
PERIOD OF RECORD                      : 1939 TO 1988
 7-Q-10 LOW FLOW                      :   [illegible] CFS

ENTER THE NUMBER OF THE DESIGN FLOW YOU WISH TO CALCULATE:
1 - CMC,  2 - CCC,  3 - USER DEFINED,  4 - EXIT
?
4
DO YOU WISH TO SAVE THE OUTPUT FROM THIS SESSION (Y/N) ...>
READY
```

QUESTIONS AND ANSWERS CONCERNING THE BIOLOGICALLY-BASED METHOD*

Q. # 1: New aquatic life protection criteria specify that the acute criteria (CMC) and the chronic criteria (CCC) may be exceeded no more than once every three years on the average by 1-hour and 4-day averages, respectively. They also state that extreme value analyses may not be appropriate for estimating the ambient exposure condition. What is an extreme value analysis?

A. This is a very broad question. There are many types of extreme value analyses. But all extreme value analytical techniques have something in common. Let's consider a time-series of daily flow data in order to explain extreme value techniques.

A low-flow water year starts on April 1 of each year and ends on March 30 of the following year. If we perform an extreme value analysis for a 4-day average condition, we should estimate 4-day running averages for each water year, then determine which running average is the lowest (extreme) for each water year. Finally, we rank the extreme value of each year for frequency analyses.

Q. # 2: Would you explain how running averages are estimated?

A. Starting with April 1, our first running average will be the arithmetic mean of flow data for April 1, 2, 3 and 4; the second running average will be the arithmetic mean of April 2, 3, 4 and 5; and the third running average will be the 3,4, etc. Thus, there will be 362 4-day running averages for each water year of 365 days.

Q. # 3: By extreme value, do you mean lowest running average of the water year?

A. In low-flow analyses, the extreme value for a water year is the lowest running average for that year.

Q. # 4: So, do I have 30 extreme values from 30 years' flow record considering one extreme value for each water year?

A. Exactly.

---

* The biologically-based design flow method has been supported by an overwhelming majority of water quality coordinators at Regional and Headquarter levels. But the method, being totally new, tends to raise a lot of questions which we have heard over time from many reviewers. Some of these questions and related answers are listed here for additional clarification to Appendices C and D of the Guidance. If this paper becomes too long, in a way it defeats its purpose. So we chose questions based on their importance. We encourage our readers to be critical about our answers and raise other questions which they may consider important. This will help us to improve both the method itself and its presentation. In this context, readers may contact Hiranmay Biswas (FTS-382-7012) or Nelson Thomas (FTS-780-5702)

Q. # 5: You said something about ranking the extreme values. How do you rank them and why do you rank them?

A. For low flow analyses, ranking can be done from lowest to highest. For a low-flow analysis of a 30-year flow record, we have 30 extreme values. If we rank them from the lowest to the highest value, and no two extreme values are equal, then we have one value for each of 30 ranks, and the return period of the first ranked flow is approximately 30 years, and that of the 10th ranked flow is approximately 3 years.

Q. # 6: The frequency analysis using the ranked extreme values seems to be quite straight forward. Why are various kinds of distributions used for frequency analyses?

A. If we are concerned with a prediction of low flow for a return period that is equal or less than the flow record, then we will not have to use any distribution at all. The distribution-free, or non-parametric technique, is the best for frequency analyses. But, suppose you need 100-, 200- or 500-year flood and drought forecasts for the design of a dam (for use power production and irrigation) and we do not have a flow record of such a long period; then, we need to use some form of distribution to extrapolate to 100, 200 or 500 years. There are many well known distributions which can be chosen on a case-by-case basis.

Q. # 7: The new WQC also make some reference to the Log-Pearson Type III distribution as an example of the extreme value analysis. While we are on the subject of distribution, is it the only distribution that is currently in use in the water quality analytical field?

A. The United States Geological Survey uses the Log-Pearson Type III distribution in low-flow as well as flood-flow analyses. They made the choice after conducting a study of flood flow analyses using various other techniques. The choice of techniques should be based on the nature of the distribution of extreme values. But, for national consistency of estimates, the USGS chose this technique.

Q. # 8: Extreme value analytical techniques are often used in the hydrologic field, and seem to be quite reasonable. Is there any biological/ecological reason why extreme value analyses are not appropriate for estimating design flow using the ambient duration and frequency of the new WQC?

A. Yes, a direct use of extreme value analyses is not appropriate because biological effects are cumulative.

Q. # 9: Would you elaborate how the cumulative nature of biological effects is related to extreme value analyses?

A. In extreme value analytical techniques, only the most extreme drought exposure event is considered, but other, less severe within-year exposure events are totally ignored, although their cumulative effects could be severe. The severity of those smaller within-year exposure events of extreme drought conditions that are ignored may outrank in severity the extreme exposure events of other less-than-most severe drought conditions. Since the biological effects are cumulative, we must find a way to account for all within-year exposures in addition to the most extreme exposure event of each year.

Q. # 10: Your answer is difficult to follow; would you give an example?

A. Hydrologists know that we had, in various parts of the USA, extreme drought events during the water years 1925-1932, 1955-1956, and during a few years in the late seventies. In other years, drought was not as severe. Suppose that in water year 1925, there were 4 very low 4-day running averages of which only one was accepted as the extreme value of that year; the 2nd, 3rd, and the 4th values were ignored. Similarly, one extreme value was estimated for each of the other Water years. But, some of the extreme values of other water years are less severe than 2nd, 3rd or the 4th running averages of the year 1925. Thus, by ignoring these 3 running averages of the water year 1925, the extreme value method has ignored potential severe effects that may result from those exposure events. In addition, the inclusion of other extreme values that are less severe than the 2nd, 3rd and the 4th running averages of the year 1925, and exclusion of more severe excursion events (2nd, 3rd and 4th excursions of water-year 1925) result in a skewed estimate of low flow.

Q. # 11: The method described to implement the two-number aquatic life criteria is called a biologically-based method. What is biological about it?

A. Almost every parameter that is used in this method is derived on the basis of either biological, toxicological or ecological considerations, whereas the parameters used in the extreme value analyses are unrelated to biological, toxicological or ecological considerations.

Q. # 12: Would you name the things that you think are biological, toxicological or ecolgoical in nature?

- durations of acceptable exposure conditions: 1 hour for CMC and 4 days for CCC are biologically derived.

- 3 years on the average is the allowed ecological recovery period after a single excursion (see Table D - 2 of Appendix D of the Technical Support Document for Water Quality-based Toxics Control (TSD)).

- 15 years is selected for ecological recovery after a total of 5 or more excursions within a low flow period (see reference Table D-2 in Appendix D of TSD).

Q. # 13: I see neither 15 years nor 5 exposure events in the referenced Table D-2. Could you explain the discrepancy?

It is true that neither 15 years nor 5 excursions are found in the reference Table. But what is available is that rivers and streams are fully recovered between 5 to 10 years after a severe exposure event. Aquatic biologists consider that repeated within-year exposures can result in catastrophic effects. In their judgement, 10 years' exposure interval is inadequate because under that situation the ecology of the receiving system will be under constant stress and recovery. By the same token, a 20-year interval was considered to be unnecessarily stringent for attaining healthy biota. After these considerations and debates among biologists and wasteload allocation coordinators, we decided to use 15 years as an acceptable interval after a severe exposure event consisting of several within-year exposures.

Q. # 14: Have you anything to say about how you decided to allow 5 excursions in an interval of 15 years?

A. WQC allow an excursion once every three years on the average. Since the effects of excursions are cumulative, ecological recovery from a severe exposure event requires about 15 years and the recovery period from a single exposure event, according to the national WQC, is 3 years. Therefore, 15/3 or 5 excursions are accepted as the upper limit of within-year excursion counts.

Q. # 15: Why did you not choose a 12-year interval for 4 within-year exposure events? Or could you not choose an 18-year interval for 6 within-year exposure events (based on the info available in Table D-2 of TSD)?

A. One could make various other choices based on site-specific knowledge but we made our choice for average conditions.

Q. # 16: If 12- or 18-year intervals are chosen for 4 or 6 within-year exposure conditions, would the design flow be different from that of the 15-year interval choice? Do we have any idea about how different the CCC or CMC flow will be for the choices of 12- or 18-year interval?

A. No, we did not perform such analyses or comparisons but our guess is that the difference will not be substantial.

Q. # 17: It is understood that, if a 15-year interval is chosen for ecological recovery, then 5 within-year exposures may be allowed because WQC specify 1 exposure on the average of every 3 years. But some extreme drought related low flow periods might include less than 5 within-year exposures, and some more severe low flow periods include more than 5 within-year exposures. If exposure effects are cumulative, why not include all exposures within a year; why limit it to 5?

A. The biological method accounts for all within-year excursions when the number of excursions during a low-flow period is 5 or less. So, 5 is the upper limit, and the lower limit is 1.

Q. # 18: What if the within-year excursions for a given flow based on the biological method is naturally greater than 5 during say, a 50- or 100-year drought? In those years, flow may remain low for a long time, such as for 40-50 days, not necessarily for just 20 days for 5 excursions. After all, we cannot change nature, can we?

A. No, we cannot change nature. But we can modify our approach to suit our objective after understanding the consequences of severe events.

We made a number of analyses to find out what happens if we account for all, not just 5, excursions that one may expect from those most severe drought years. We found that inclusion of all excursions from those years results in the following:

- Design flows of all return periods of say, 3, 5, 10, 20, 50 years, etc. are completely dominated by those most severe drought years; and
- this leads to extremely stringent design flows.

Q. # 19: There is nothing biological in these analyses. Since the exposure effects are cumulative, should we not count all exposures regardless of how rarely one may expect them, or how stringent the resulting design flow is?

A. This is where a little understanding of ecological recovery and familiarity with the North American aquatic life are necessary to make a reasonable choice. The upper bounds of the life cycles and life spans of most North American aquatic species are 2 and 10 years, respectively. An exposure event of 20- or 50-year interval may not be meaningful, particularly when one considers other ways, for example recruitment from the surrounding ecosystem, in which recovery may take place. So, in our judgement, a recovery period of 15 years is adequate for situations where the number of exposures in a low flow period is 5 or more.

Q. # 20: What is described here in the biological method is similar to what is done by hydrologists for partial duration series. They address the problem using traditional statistical approach. Why did you not use a classical statistical method?

A. First, the statistical science of partial duration series, particularly in the hydrologic field, is not well developed. Not many people understand it. Although the biological method lacks statistical elegance, it is simple and can be used and understood by field biologists and engineers, alike. We would not be surprised if a statistician comes up with a better statistical answer for the problem that we have in hand. But it would be important for the regions to understand most aspects of the method if we expected them to use it.

Q. # 21: Over the last 20-25 years, the majority of the states in the U.S. used the 7Q10 low flow as the design flow for what we essentially had as a not-to-be exceeded single number WQC value. It seems that it worked fine, although a rationale for such a choice is hard to come by. Why is it so important now to have a rational biologically-based method to implement the two-number WQC?

A. It is important to provide a rational method for three major reasons. First, lack of a biologically-based method in the past led to the adoption of design flows such as 3Q20, 7Q10, 30Q10, 30Q2, and even the annual average flow for identical water use. A technically defensible method will bring about technical consistency for any desired level of protection. Second, the introduction of the two-number national WQC, whole effluent toxicity, and the guidance on site-specific water quality standards have unalterably changed the environment of toxics control. In these situations, a biologically-based method is necessary that can be applied not only to national two-numbered WQC, but also to other site- and use-specific durations and frequencies of pollutants and whole effluent toxicities. Third, since WQC and their field use have become complex, it is very important that we develop a simple method that is easily understandable to field biologists and engineers, alike. In the past, very few understood the relation between the WQC and the corresponding 7Q10 or other xQy design flow.

Q. # 22: Why is the biologically-based method considered to be more directly based on the water quality criteria than the hydrologically-based method?

A. In the biologically-based method, both the averaging period and the frequency (for example, 4 days and 3 years) are taken directly from the criterion, whereas in the hydrologically-based approach, the two numbers in XQY are not. Most of the other aspects of the biologically-based approach are also based on biological, ecological, and toxicological considerations. One of the major technical differences between the methods is that the 3 years in the biologically-based method is an average frequency, whereas the 10 years in the hydrologically-based approach is a return period.

Q. # 23: Does it make any difference whether biologists, ecologists, and toxicologists understand how design flow is calculated?

A. Yes, for three major reasons. First, these are the people who derive the aquatic life criteria. If the criteria are not used in a manner that is consistent with their derivation, the intended level of protection will probably not be achieved. Second, site-specific frequencies and durations will not correctly affect design flow if the duration and frequency are not directly used in the calculation. Third, if they understand what parameters affect design flow, biologists, ecologists, and toxicologists can gather data that might allow them to refine their estimates of such values as one hour, four days, three years, and fifteen years.

Q. # 24: Let us discuss the simplicity of the biologically-based method. I am not clear how an excursion is counted. Would you explain how you count excursions and estimate design flows?

A. This is the key to understanding the biologically-based method. Since the stream flow is inversely proportional to instream concentration, any consecutive 4-day average of low-flow that is lower than the design flow is counted as one excursion of the CCC. The following is the step-by-step explanation of how excursions are counted in estimating x-day y-year design flow:

1. An excursion period is defined as a sequence of consecutive days where each day belongs to a x-day average flow that is below the design flow. For example, if the three running averages of a consecutive 6-day period are less than the 4-day 3-year design flow, then those 6 days belong to an excursion period.

2. The number of excursions in an excursion period is the length of the period divided by the criteria averaging period. For example, if an excursion period is 6 days long, then the number of excursions for the 4-day averaging period for CCC is 6/4 or 1.5.

3. The total number of excursions is limited to 5 within a low flow period. Usually a low flow period lasts 120 days or less. In some rare stream situations, more than one low flow period within a water year is possible.

4. The allowed total number of excursions over the period of record is the number of years of record divided by the frequency of aquatic life criteria (3 years for the CCC of the new national two-number criteria). For example, if we have a 30-year flow record, then total number of excursions that are allowed for x-day 3-year criteria is equal to 30/3 or 10.

5. The 4-day 3-year design flow for the 4-day 3-year CCC based on a 30-year flow record of a given river is equal that flow which results in no more than the allowable number of excursions. For example, the total allowable number of excursions for the given record is 10. The design flow is the highest flow that results in no more than 10 excursions calculated as defined in steps 1 through 4 above.

Q. # 25: Let us take the example printout (from page D-5) for the Amite River as presented below. Will you explain the procedure using this example?

A. As shown in the following printout, we have a flow record from 1937 to 1983 which is approximately 42 years. Since we are allowed to have no more than one excursion in every 3 years on the average, we have 42/3 or about 14 excursions. In October 1952, we encountered the first excursion for a continuous period of 6 days. Thus, we calculate 6/4 or 1.5 excursions for that low flow event. The next excursion period occurs, starting from October 10, 1956, for 30 consecutive days. Since the upper limit of excursions in a low flow period (a low flow period is usually 120 days long) is 5, we

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible] 30, 1952	1.30	OCT 30, 1952	8	1.7
OCT 10, 1956	3.00	OCT 10, 1956	30	[illegible]
OCT 16, 1963	1.00	OCT 16, 1963	30	[illegible]
		[illegible] 11, 1963	10	[illegible]
[illegible] 27, 1969	2.50	[illegible] 27, 1969	10	[illegible]
[illegible]	10.00			

obtained a total of 5 excursions only, although in reality there were altogether 30/4 or 7.50 excursions in that low flow period. Similarly, we found only 5 excursions for total period of 30 days during the low flow period of 1963. In 1969, we had 2.5 excursions for a low flow period that lasted for 10 days.

Q. # 26: It seems like the accuracy of the design flow estimates is totally dependent on the length of the flow record. Do you agree with this observation?

A. Absolutely. This is true about any analysis. More relevant data are necessary to provide more accurate information.

Q. # 27: What minimum length of flow record is recommended?

A. The longer the flow record, the more reliable the estimated design conditions will be. Figure E-1 shows how the spread in the 90% confidence limits on the extreme value-based design load with 10-year return period decreases with increasing period of record. (This figure was derived on the basis of lognormal statistics, not log Pearson type 3). Results are shown for both low variability (CV=0.2) and high variability (CV=0.8) situations. Based on the behavior of these curves, it appears that 20 to 30 years of record is a reasonable minimum requirement for extreme value analysis at a 10-year return period.

The case for the biologically-based excursion criterion is less definitive. However, since it considers all days within the period of record as its sample (not just the worst condition of each year), its sample size is much larger than that of an extreme value analysis. Thus, it may be possible to use periods of record less than 20 years with this criterion and still have a good level of confidence in the results.

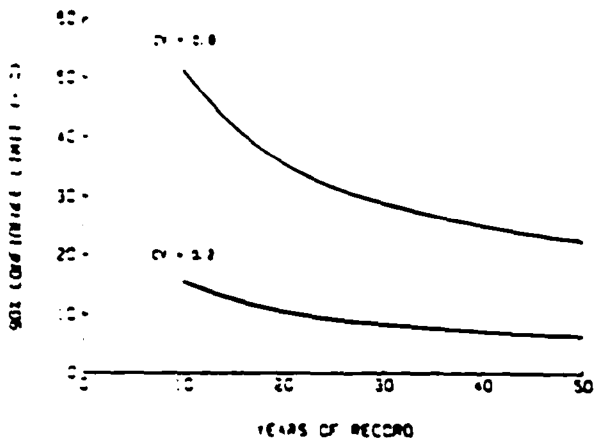

Figure E-1. Spread in 90% Confidence Limits on Estimating a Quantity with a 10-year Return Period as a Function of the Record Length (Derived from tables in Stedinger (1983))

Q. # 28: What would you do for intermittent streams where low flow is zero during low flow periods? Also, how will you use the biologically-based method in situations where flow data are not available?

A. These are problems that are generic to all flow estimating techniques. For intermittent streams for which the low flow is zero, the design flows for CMC as well as CCC are equal to zero. In situations where flow data are not available, field hydrologists and engineers sometimes use flow data from hydrologically comparable drainage basins.

Q. # 29: The table given in Question 23 looks simple. How much time does it take to conduct a biologically-based analysis for any stream of interest?

A. The analysis is performed in two steps. First, daily flow data are retrieved from the daily flow file in STORET, by submitting a batch job. This will take a few minutes of time at the computer. However, the job run might take anywhere from a few minutes to several hours, depending on how busy the computer system is at the time of submittal. Once the data has been retrieved, the analysis can be performed in five or ten minutes.

Q. # 30: It seems that the foundation of the information about ecological recovery periods for the two-number WQC is all that are listed in Table D-2 of the TSD. But, anybody familiar with these references will tell you that the recovery periods listed in that table are related to recovery from catastrophic exposures caused by spills, not by effluents of malfunctioned advanced treatment facilities. Would you agree that this is not a satisfactory set of information to make such an important decision?

A. This is the best available information that we could use to estimate ecological recovery. Considering the complexities involved in the implementation of the two number WQC, and the site-specific WQC for pollutants and whole effluent toxicity, we could not leave the recovery question open to anyone's interpretation. Considering the potential for misuse of the WQC in their implementation phase, we had to use our best judgement and the best information available, although we recognize that our best judgement would be debatable. Since the information base is not as strong we want to have, in keeping with the Agency policy and legal background, we had to go in the direction of protection in the over-all decision making process.

Q. # 31: What are you doing to improve the information base?

A. ORD is planning to undertake a major effort before the next update of the WQC. But, this is an area in which success is dependent more on cooperative efforts in which field biologists, ecologists, toxicologists, engineers and hydologists share their experience than doing mere literature reviews and/or gathering laboratory-generated information.

REFERENCE

1. Stedinger, J.R., "Confidence Intervals for Design Events", Jour. Hyd. Eng. Div., ASCE, Vol. 109, No. 1, January 1983.