EVALUATION OF DESIGN FLOW CRITERIA FOR EFFLUENT DISCHARGE PERMITS IN COLORADO

by

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ABSTRACT

The criteria for appropriate design flows for NPDES permits in the State of Colorado are based on the requirements of the most sensitive water use, which in most cases is aquatic life. Alternatives to annual 7Q10 have been analyzed with respect to flow magnitude, level of protection, and potential economic impact on dischargers. The choice of acute and chronic design flows must take these factors into account in addition to the biological requirements of aquatic life communities reflected in water quality criteria.

In this investigation it was found that the design flows meeting the criteria currently recommended by the U. S. Environmental Protection Agency were the annual 1Q10 for acute flows and 7Q10 on 7Q15 for chronic flows. These design flows are very restrictive and do not take advantage of the assimilative capacity of the stream.

It was also found that monthly or seasonal design flows offer the possibility to increase the use of assimilative capacity and still maintain existing instream uses. The choice of whether to use monthly or seasonal design flows (rather than annual) may be a compromise between increased complexity of implementation and greater utilization of assimilative capacity. The differences between annual and monthly design flows are much greater than the differences between annual and seasonal design flows. Therefore the use of monthly design flows could result in substantially higher effluent permit limits than seasonal or annual flows, depending on the number of flow excursions allowed. The ability of dischargers to adjust their treatment processes on a monthly basis and the increased complexity of implementation, however, may discourage the use of monthly low-flow criteria.

A water quality control program based on the number of streamflow excursions is not the same as one based on the number of water quality excursions. For example, in the case of unionized ammonia, the sensitivity of the concentration of unionized ammonia to the combination of pH and temperature is so strong that in many cases the streamflow has little effect on whether or not the water quality standard is violated. A given design flow will therefore not guarantee that a water quality standard will not be violated.

This report gives very good estimates of the magnitude and frequency of low-flow events in the several streamflow reaches analyzed in Colorado. With the uncertainty of these parameters thus removed, it may be prudent for municipalities or industries in these reaches to reasses their effluent limitations. For example, the frequency distributions of the upstream and effluent unionized ammonia concentrations may allow the effluent limit to be raised.

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CHAPTER 1 - INTRODUCTION

The objective of this study was to investigate alternative design flows to the annual 7Q10 statistic for use in determining discharge permit limits in the State of Colorado. The purpose of looking at alternative flows was to reduce wastewater treatment costs by using the assimilative capacity of streams more fully, while maintaining existing downstream water quality.

The study research plan included the following steps:

1) literature review
   a. federal and state regulatory requirements and procedures used in discharge permitting;
   b. alternative approaches used in discharge permitting throughout the nation; and
   c. methodologies used in low-flow analysis.
2) site selection and review;
3) data acquisition;
4) flow data analysis;
5) comparison of alternative design flows
   a. theoretical effluent limits;
   b. cost of treatment.

An interim report was published in January, 1986 as part of this study to provide background information. A short summary of each of the three parts of the interim report is given below.

Review of Federal and Colorado State Legislation and Regulations on Effluent Discharge Permitting. Water pollution control in the United States is based primarily on the Federal Water Pollution Control Act of 1972 (P.L. 92-500) (as amended in 1977 by the Clean Water Act (P.L. 95-217) and in subsequent years). The Clean Water Act requires water quality standards to be established for the Nation's waters and provides for the National Pollutant Discharge Elimination System (NPDES) to enforce these standards. In Colorado, the federal NPDES is administered under a state version of the program called the Colorado Discharge Permit System (CDPS).

Streams in Colorado have been divided into specific segments which have been assigned one or more use classifications according to existing or potential future uses. Water quality criteria are defined as the maximum levels of pollutants which may be allowed in rivers and still protect designated uses. To ensure that water quality criteria are met and uses are maintained, the CDPS regulates the discharge of pollutants from point sources within the state.

Water quality-based permit limits are calculated by using a steady state mass balance model. The model is solved for effluent concentration which generally becomes the permit limit. Factors considered in the model include upstream flow, ambient stream pollutant levels, effluent flow, and water quality criteria. The upstream flow value traditionally accepted for use in the calculation of permit effluent limits is the 7Q10 (the seven-day moving average low flow that occurs once every ten years on the average). The Federal Clean Water Act makes no specific provision for the use of the

7Q10, but rather provides flexibility for the states to develop their own water quality management programs to meet specific state needs. The use of some other low flow value to determine CDPS permit limits may actually be more cost effective while still maintaining river water quality.

Alternative Approaches to National Pollutant Discharge Elimination System Permitting. The delegation of authority for water pollution control under the NPDES, leaves the states with a high degree of flexibility to establish their own water quality programs and discharge permit systems to meet the goals of the Clean Water Act. Recently, the EPA's Office of Policy, Planning and Evaluation and individual states have sought out innovative approaches to water pollution control permitting which will maintain or improve existing water quality with minimum construction and operation costs.

There are two major types of innovations in NPDES permitting. The first type includes variations of permitting techniques which enable a fuller use of stream assimilative capacities while still maintaining stream standards. Examples are the changing upstream design flow frequency/duration statistic, water quality standards, effluent flow, and timing of effluent release. The second type involves reallocating waste loadings through discharge allocation trading to achieve the most economical allocation. Examples are point source trading, point/nonpoint trading, and banking.

Innovative approaches are currently incorporated into approximately one-fourth of all State of Colorado discharge permits (225 out of 900 total). Alternative permitting techniques have been applied in Colorado in five major areas: seasonal design flows, site specific water quality standards, discharge allocation trading, controlled release, and poundage based limits. Real time permits have been proposed, but have not yet been implemented. Considerable potential exists for future use of alternative techniques in NPDES permitting in the State of Colorado, particularly as applied to streams of environmental and economic importance. Further development and implementation of innovative approaches should be focused on those techniques currently applied in Colorado and real time permitting.

Summary of Low Flow Statistics for Selected Colorado Streams. Based on a review of daily and routine flow and historical water quality data records, seven stream sites were selected for study. The stream sites cover a range of discharge types, hydrologic characteristics, and degree of man's impact (e.g. diversions). Comparisons of summary statistics, frequency/duration statistics, and frequency of exceedance statistics were made within and between rivers.

The description of low flow conditions allows for better determination of how to group months into seasons and the importance of background water quality during low flow periods. Factors that affect the use of low flows in the permit process are: hydrologic, diversions, flow routing, extrapolation of low flow statistics, and errors in estimates of low flow data. The summary points of the report are:

1. There were two types of streams in terms of the effect of changing the annual duration/frequency statistics, one group (Blue River near Dillon, Coal Creek near Plainview, St. Vrain at Lyons, and Cache La Poudre at Fort Collins) showed very little change in the estimated flow value for different annual duration/frequency statistics. For these streams, the apparent method for changing the upstream design flow would be to examine and propose seasonal flow statistics. The second group (Clear Creek near Golden and South Platte at Littleton and Henderson) did show

changes in the estimated flow value for different annual duration/frequency statistics. For these streams, changing both the annual and seasonal flow statistics should be examined.

2. There appear to be three groups of months based on whether the flow in the month is low flow, high flow, or a transition between low and high flow. The low flow months for all streams were December, January and February; with the months of November and March usually low flow months. The grouping of months into seasons to allow the estimation of seasonal flow statistics should also take into account any seasonal patterns that may exist in stream water quality.
3. Most of the streams exhibited large lag one autocorrelations for both mean annual and monthly stream flows. The annual correlation suggests that low flow years tend to be grouped together and the monthly correlation suggests that for any given low flow year there may be numerous excursions for a particular flow statistic. This pattern results in some design flow criteria to have a different level of protection for different years.
4. The quality of applying low flow statistics as upstream design flow criteria in the wasteload allocation process is dependent not only on choosing the appropriate flow statistic, but also on the amount of uncertainty in the estimated low flow statistic. Factors that affect the amount of uncertainty in the estimated low flow statistic are: flow measurement errors, differences between stream gage location and point of effluent discharge, and statistical estimation of the low flow statistic. Without some measure of the amount of uncertainty in design flow criteria there exists a state of doubt as to the level of protection provided to the aquatic life community.

CHAPTER 2 - METHODOLOGIES OF LOW-FLOW ANALYSIS

FACTORS AFFECTING LOW FLOWS

Low flows are affected by a number of natural and human factors. These factors may affect both the quantity and timing of low flows, and may produce short- or long-term changes in low flow regimes.

Natural Factors

The natural factors that determine low flows for a given catchment can be grouped into four main categories based on: climate, vegetation, hydrogeology, and morphology. Climatic factors include precipitation, evapotranspiration, and temperatures. Precipitation directly affects the quantity of low flows. Evapotranspiration also may largely determine the quantity of low flows, particularly during dry periods. However, for rivers that are fed exclusively by groundwater, the effect of evapotranspiration is minimal (McMahon, 1985). Temperature may affect low flows during the cold winter season in Colorado. Freezing of water in the ground and in stream channels reduces discharges, causing low flows (McMahon, 1985). Vegetation may affect low flows reducing runoff and increasing infiltration, or by increasing evaportranspiration.

Hydrogeologic factors include geology and groundwater. Geology is considered an extremely important factor in determining low flow regimes

(Riggs, 1976). Highly porous, permeable geologic formations like unconsolidated sands and gravels transmit more groundwater at faster rates than impervious formations. Infiltration capacities determine recharge and runoff quantities. Groundwater frequently provides the primary source for streamflow during low-flow periods. In general, groundwater flows gradually decrease throughout the low-flow season as storage is depleted. A relatively stable minimum flow may eventually be reached, depending on the sources of groundwater flows (McMahon, 1985). In some cases, rivers actually lose water to the groundwater system rather than being fed by groundwater. Influent rivers may exhibit completely different low flow regimes as a result.

The effect of geology and groundwater on low flows is significant, yet very difficult to define. Seepage runs are one technique that may be used to detect major gains or losses to a river system (Riggs, 1972). A seepage run is conducted by measuring streamflow at intervals along a given reach during a period of base flow. Increases or decreases may be attributed to groundwater, if all other factors are held constant. Studies have been made in Colorado at a number of specific sites to quantify the effects of groundwater on streamflows, and have shown that flows are often inconsistent and difficult to predict accurately. Lewis presented predictions of groundwater flows into segment 15 of the South Platte River that ranged from 3.9-6.8 cfs/mile (1986). This study was based on six seepage readings taken by the USGS during the years 1966-1968. However, more studies are necessary to better define the relationships between groundwater and stream systems in Colorado.

Morphological factors that may affect low flows include: size, relief, and water bodies. The drainage area of a stream basin is considered by many to be a major factor in determining streamflows, particularly in humid environments (McMahon, 1985; Riggs, 1976, Singh, 1974). Relief factors, such as basin slopes and elevations, may affect runoff and infiltration characteristics which help to define low flows. The presence of lakes, reservoirs, or irrigation channels may influence low flows by feeding groundwater systems or by altering climate.

Human Factors

Man-induced changes are evident in many streams throughout the Front Range of Colorado, particularly during low flows. The major ways that human activities have affected streamflows include: urbanization, construction of dams and reservoirs, agricultural development, and irrigation. Although changes in flow regimes are to be expected, the question of concern is whether or not the changes affect elements specifically related to low-flow characteristics (Riggs, 1976).

Urbanization produces greater impervious area which generally results in more runoff, shorter time to peaks, higher peak discharges, and less infiltration to recharge groundwater flows. Urbanization may bring increased needs for diversion of water or pumping of groundwater for public or industrial uses. In addition, urbanization may result in increased discharges of effluents from municipal wastewater treatment plants or industrial plants. The overall effects of urbanization on low flows may be mixed. Increased impervious area may produce lower minimum flows, while discharges may increase low flows, particularly if the source of the discharge is from deep groundwater (McMahon, 1985; Riggs, 1976; Singh, 1974). In basins where the impervious area constitutes only a small percent of the entire drainage basin area, the effect of urbanization on low flows may be minimal (Riggs, 1976).

The construction of dams and reservoirs may influence low flows in a variety of ways. The significance of the effects of a dam varies, depending on the purpose of the dam and degree of flow regulation. Generally, low flows directly downstream from the dam are equal to the design minimum flow (Singh, 1974). However, effects further downstream may be substantially different from those directly downstream from the dam and are more difficult to predict (Riggs, 1976). A reservoir may reduce downstream flows below natural levels by increasing losses due to evaporation, or may increase low flows by feeding groundwater systems that add to the river downstream (McMahon, 1985).

Agricultural development and irrigation diversions affect low flows indirectly by influencing evaporation, infiltration, and runoff characteristics. These effects are particularly important along the Front Range of Colorado. Irrigation water is often supplied by stream diversions. These diversions are the controlling factors for low flows during the crop season in some streams. Frequently, water rights have been allocated to the point where a stream may legally be dried up and may have zero flows. Return flows from irrigated agriculture via groundwater or surface runoff may increase low flows to streams located within a certain distance. However, little water that is applied to irrigated areas is actually thought to return to streams (McMahon, 1985). Much of the water applied to irrigated fields is lost to evapotranspiration.

The greatest influence of irrigated agriculture on minimum streamflows occurs during years of low rainfall. During these periods, irrigation is at a maximum and low stream levels may require pumping of groundwater to supply irrigation, potentially lowering flows even further.

GENERAL CONCEPTS AND TECHNIQUES USED IN LOW FLOW ANALYSIS

Moving Averages

Low flows may be calculated for durations of one day or longer. Low flows of durations longer than one day are generally calculated as moving averages of a series of daily flows. The moving average acts as a smoothing function for a daily flow record to reduce the effects of extreme variability, particularly of zero or very low instantaneous flows. An x-day moving average is calculated by averaging daily flow values for days 1 to x, 2 to (x+1), 3 to (x+2) etc. For an annual period of record, 365 daily values would be smoothed to (365-x)+1, x-day moving averages. The date of occurrence assigned to a given moving average is the middle day of all the days included in the average.

Acute and Chronic Design Flows

Design flow is the term currently applied by the U.S. EPA to designate the upstream dilution flow to be used in discharge permitting. The limiting factors that generally determine the design flow are the requirements of the aquatic community being protected. Design flows may be calculated for acute or chronic levels of exposure of the aquatic environment to pollutants.

Acute design flows are generally based on maximum concentration levels, which are intended to protect aquatic life from unacceptable short-term effects. The U.S. EPA rationale for acute and chronic design flows is given in the 1985 EPA Guidelines for Developing National Water Quality Criteria (Stephan, 1985). The acute concentration used by the U.S. EPA is the Criterion Maximum Concentration (CMC), which is equal to one-half of the Final Acute Value (FAV). The FAV is a value based on laboratory toxicity test results (i.e. 48- or 96-hour LC50). The CMC is intended to provide a "reasonable level" of protection for aquatic life. This level has been defined by the EPA as protection of all except a small fraction of the taxa present (or 50 percent of the population of the most sensitive 5 percent of the species present) (Stephan, 1985). The duration of exposure deemed by the U.S. EPA to be appropriate for acute levels is one hour, a short enough period to avoid large fluctuations in pollutant concentration. In practice, the duration used is one day, because discharge data are not often available on an hourly basis.

Chronic design flows are generally based on a concentration lower than the acute level, which is designed to protect ecosystems from unacceptable effects due to long-term exposure. The chronic concentration used by the U.S. EPA is the Criterion Continuous Concentration (CCC), which is equal to the Final Acute Value divided by the Final Acute-to-Chronic Ratio. Acute-to-Chronic ratios have been determined in the laboratory and range from one to more than a thousand, depending on the toxicity characteristics of the water quality variable. The duration of the chronic design flow is longer than one day, usually taken as a moving average of four to thirty days. Four days is the duration that has been recommended initially by the U.S. EPA, but longer durations (7-day or 30-day) may be justified for relatively stable flow and downstream water quality conditions. The criterion used by the U.S. EPA to justify the use of a 30-day average for chronic design flows is that the coefficient of variation (mean discharge divided by the standard deviation) based on the complete record of daily flows be approximately one or less. Other criteria that may be more appropriate include the coefficient of variation based on low flows only, instream water quality variations or effluent quantity and quality variations.

Recurrence Intervals

The recurrence interval of a given flow event is a measure of how often it is expected to occur, and is equal to the inverse of the frequency of occurrence of the event. For example, if the frequency were once in ten years or 10 percent, then the recurrence interval is ten years. The allowable frequency of acute or chronic flow events recommended by the U.S. EPA is once every three years, although this value may vary depending on the aquatic ecosystem being considered. Justification given by the U.S. EPA for the three year period is that it has been deemed sufficient for most aquatic ecosystems to recover from damage caused by adverse water quality conditions (Stephan, 1985). The three years recommended by the U.S. EPA is actually meant to be longer than the average recovery period so that ecosystems are not in a constant state of recovery (U.S. EPA, 1986). Frequencies greater than once every three years may be justified on a site-specific basis for particular aquatic ecosystems.

In the case of a prolonged drought with many single low-flow events, a frequency of once every three years or once every two years may not be appropriate. For instance, if a string of 10 low-flow events occurred in a single year, then the frequency of once in three years would require a recovery period of 30 years without another single low-flow event. As an alternative, the U.S. EPA has recommended the use of a maximum period of recovery of 15 years after a drought period. The justification for 15 years is that an ecosystem requires between five and ten years to recover after a severe stress like a drought, and an ecosystem should not be in a constant state of recovery. Thus, 15 years was deemed by the U.S. EPA as an "appropriate stress-free period of time" after a severe drought (U.S. EPA, 1986). In the case of a drought then, no more than 15 years can be required before the next allowable low-flow events that occurred during the drought. The maximum period required for recovery after a drought can vary and other values can be justified by site-specific analysis.

Period of Record

The recommended period of record for low-flow frequency/duration analysis is 30 years or more of daily flows (McMahon, 1985). If 30 years is not available, a minimum of 10 years of daily flow data may be used to produce valid results (U.S. Interagency Advisory Committee, 1982). Frequency analysis of a period of record shorter than 30 years could produce results with larger probable errors and may introduce bias if the short-term record includes a predominance of wet or dry years (McMahon, 1985; Searcy, 1959). The period of record for biologically-based low-flow analysis may be shorter than 30 years and still produce results with a good level of confidence (U.S. EPA, 1986). Because biologically-based analysis considers all days within the period of record and not just the single extreme low flow for each year, the sample size is much larger than that of frequency analysis, and so a shorter data record is sufficient. Whenever possible, a period of 30 years of data was utilized for frequency/duration and biologically-based analysis in this study.

One important consideration in the determination of an appropriate length of record to use is the homogeneity of flow data. If data are non-homogeneous, then the advantage of a longer, more representative record is offset by the disadvantage of inconsistent data. Both homogeneity and representativeness should be weighed in the determination of the period of record for analysis. These factors are discussed further in the section on data assumptions.

Periods of Analysis

The analysis of low flows in this study was carried out for three different periods of time - years, seasons and months. The purpose of monthly and seasonal analysis was to more accurately reflect low flows during all times of the year, rather than just during the lowest flow periods.

Annual Low Flows and the Climatic Year

Annual low-flow analysis is based on the single lowest moving average flow for each year of record. Usually, the period of record is broken up into distinct year-long segments rather than analyzing the entire continuous period of record. A flow record may be separated into water years (October 1-September 30), climatic years (April 1-March 31) or calendar years (January 1-December 31). Both the climatic year and the water year are identified by the year in which the period ends (e.g., the climatic year April 1, 1955-March 31, 1956 is denoted as 1956). The period of annual low-flow analysis should be chosen so as to include the low-flow period entirely within a given year. Generally, flood flow analysis is made on the basis of the water year. The climatic year, however is more appropriate for low-flow analysis since a low-flow period rarely occurs in late March-early April (ASCE Task Committee, 1980; Riggs, 1972; Petsch, 1979). In some cases, other annual periods may be more appropriate than the climatic year, depending on the pattern and timing of low flows at a particular site. For this study, annual low flow analyses were made on the basis of the climatic year.

Monthly Low Flows

Monthly low-flow analysis is based on the single lowest moving average flow within each of the 12 months of the year for each year of record.

Thus, there would be 12 different monthly low flows (April-March) as compared to one single annual low flow. The lowest monthly low flow for each year should be equal to the annual low flow for the same years. Other monthly low flows reflect wetter periods of the year and may be substantially higher than the annual low flow.

The procedure generally used to calculate monthly low flows is similar to that used for annual flows. Each month of the year is evaluated separately for minimum flows. The calculation of monthly or seasonal x-day moving average flows with this approach presents certain problems because the period of analysis is short relative to the moving average duration. Monthly moving averages calculated with standard techniques tend to be biased toward flow values occurring in the middle of the month. This is because values in the middle of the month are included in more moving averages than values occurring at the beginning and end of the month. Another problem is that the calculation of moving averages for 12 separate months of the year using standard procedures produces fewer moving averages for the entire year than annual analysis does. For example, the calculation of monthly 7-day moving averages would produce 293 values in a monthly analysis as compared to 359 flows calculated on an annual basis.

To deal with these problems, monthly moving averages for this study were calculated with an overlapping procedure. Flows from the end of the previous month and the beginning of the following month were used in the calculation of moving averages for a given month. For monthly 7-day moving averages, three days were used from each of the previous and following months. For 4-day averages, two days were used.

Seasonal Low Flows

For seasonal low-flow analysis, months can be grouped together as low, high and transition flow seasons. In this study, months were grouped together on basis of flows only, for descriptive purposes. Other factors, such as seasonal water quality and effluent quality, also determine downstream water quality and should be considered in actual applications. Flow criteria used to split out the seasons included statistics on monthly 7-day moving average low flows (mean, median, standard deviation) and monthly 7Q3 statistic low flows. On the basis of these criteria, the months generally seem to separate fairly well into distinct high and low flow seasons. Certain other months exhibit flows that are inconsistent from one year to the next and are more difficult to group conclusively. These months have been deemed as transition seasons.

The grouping of months into seasons has a significant effect on the values of the seasonal flows. The incorrect grouping of a transition month with a high-flow season may reduce the flows drastically, particularly if the low flows occur within the high-flow season for some years and in the transition month for the other years. The selection of seasons may actually require a two-stage process. The first stage consists of an initial selection of seasons and calculation of seasonal flows, and may be followed by a second stage if it is necessary to adjust the seasons. The initial selection is somewhat subjective, but can be verified with the actual calculation of seasonal flows.

The selection of seasons requires site-specific analysis because the patterns of low-flow events may differ significantly from one site to another. In addition, flow patterns may even differ from one duration flow to another (i.e. the ideal 1-day low-flow seasons may not be the same as ideal 7-day low-flow seasons). For practical purposes, one set of seasons should be chosen for each site by balancing all the factors involved.

Zero Flows and Missing Data

Analysis of daily flow records with zeros is problematic because it is difficult to fit log-distributions to sets of data with zeros (Jennings, 1969). For this reason, zero flows should be replaced by non-zero values. Two approaches may be used to transform zero flows. The first is to add a small amount (e.g. 0.1 cfs) to each of the discharges in a given flow record (Tasker, 1972; Jennings, 1969). One disadvantage of this method is that the arbitrary addition of a constant value may change the characteristics of the flow distribution. A preferred, though more complex, approach is to use conditional probability to determine appropriate values to replace zero flows. This method involves fitting a distribution to events greater than a given base flow and predicting values based on a ratio of the number of events greater than Q_b to the total number (Jennings, 1969). None of the sites in this study actually exhibited zero flows so that neither approach described here was required.

Flow records with missing data may be completed by estimating the missing values. One approach to estimating missing data is to interpolate between the surrounding values just preceding and just following the missing value(s). If the duration of missing data is longer than several days, interpolation may not be an appropriate method and another method may be required.

Extension of Short Period of Record/Ungaged Sites

The estimation of low flows at a specific point of interest (an effluent discharge point) for use in discharge permitting is often very difficult. Rarely is there a set of discharge data of sufficient length available in the vicinity of the outfall that can be utilized. The problem is compounded in the western U.S. where the nearest gaging station may be many miles away from a discharge point and where there may be many unmeasured tributary streams and irrigation diversion points between. In addition, the role of groundwater is usually not well defined. Determinations of whether a stream is influent or effluent as well as quantitative estimates of groundwater flows are difficult to make. Changes over time of flow characteristics further complicate the analysis. For this study, the majority of the sites were selected at existing USGS gages with long records. Three sites, however, did not have long gage records nearby, and required significant effort to develop a flow record appropriate for analysis.

A number of methods have been used to extend short period of record or to develop flows at ungaged sites for analysis of low-flow characteristics. Methods include: regression analysis, water balance procedures, and regionalized analysis (McMahon, 1985; Salas, 1980; Riggs, 1972; Searcy, 1959).

Regression analysis can be used to extend a short period of record at a site by developing a relation between flows at the point of interest and flows at one or more nearby gage sites with longer periods of record. The relation can be used along with the records at other sites to predict flows at the point of interest for ungaged periods.

One of the assumptions inherent in regression analysis is normality of the data set. Frequently, flow data used in regression analysis is transformed to a normal distribution through a log-transformation, though this is not always necessary. Certain biases may be introduced with log-transformations, which may result in low estimates. The effect of this bias, however, is very small for low-flow estimates and is generally considered insignificant for low flows (Beauchamp, 1973). For regression analysis of low flows it may be desirable to limit the analysis to low flows below a certain cut-off level, rather than using a log-transformation. This approach would help to remove bias introduced by high flows, though it may not strengthen the normality assumption.

Regression equations can be developed for flows of durations ranging from one to several days, or for specific monthly or annual flows of given durations (e.g. monthly 7-day low flows). A regression equation for daily flows may be used to generate a daily flow record at a site which can subsequently be analyzed statistically as a gaged site would be. One weakness of regression analysis based on daily flows or flows of slightly longer durations is that the events are not independent from one another and may introduce some bias due to serial cross correlation. To avoid this error, regression analysis may be made for monthly or annual low flows which exhibit a greater degree of independence. However, regressions of monthly or annual low flows may be more difficult to make because of the limited number of data points available. For example, if a three-year period of concurrent record is available, then a regression of annual 7-day low flows would be based on only three data points. In this case, it may be that the violation of the assumption of independence using daily flows is offset by the added benefit of many more data points upon which to base the regression.

If regressions are to be made for monthly or annual flows, it is important that the flows being predicted correspond to the flows used to generate the regression equation being applied. For example, to define a monthly 7Q10, a regression equation developed to predict monthly 7-day low flows may be used to generate values for each month of record, which could in turn be analyzed statistically (using a fit to a Log-pearson type III distribution or other method) to determine the 7Q10. However, the same equation should not be used to take a monthly 7Q10 from one site to predict the monthly 7Q10 at the point of interest.

A measure of the ability of a regression equation to predict flows accurately is given by the coefficient of variation, or r^2 value. This value is generally calculated for each regression equation as part of the analysis. The minimum r^2 value recommended to indicate a reasonable fit of the equation to the data set is approximately 0.65, which is based on a correlation coefficient, or r value, of 0.80 (McMahon, 1985; Riggs, 1968).

Other measures of the accuracy of estimated flow records can be made for sites with short periods of record. One method involves F and t-testing to compare predicted to actual flows. As will be described in the following section on homogeneity of flows, F-test results indicate significant differences between the variances of two sets of data, and t-tests show significant differences in the means. Another way to evaluate the accuracy of predicted flows is to compare summary statistics for actual and predicted flows, statistics may include: mean, median, standard deviations, minimum and maximum values, confidence intervals, skewness, and Kurtosis (definitions of terms are given in the glossary). Perhaps the most reliable evaluation of the accuracy of predicted flows is a consideration of their physical significance and their relation to flow conditions observed at the site. For low-flow analysis, the results predicted by a regression equation should be valid particularly at low flows including a flow of zero at the gage being used for predictions.

A water balance procedure can be used to route flows from a gaged site to a site that is ungaged or has a short period of record. All sources and losses between the gaged site and the point of interest must be quantified and accounted for in the analysis. Sources may include tributary flows, effluent discharges, returns from irrigation, or groundwater recharge. Stormwater runoff may also act as a source, but is generally insignificant in low-flow analysis. Losses may include diversions, or groundwater outflows. Daily flow data are rarely available for all of these factors and estimates must often be made from monthly or even less frequent data.

A third approach, regional analysis, has been used with limited success to predict low flows at ungaged sites. The regionalization method is based on the premise that low flows can be predicted through an analysis of the regional factors affecting streamflows including: basin drainage area, precipitation, geology, groundwater flows, relief, and vegetation.

FREQUENCY ANALYSIS

Frequency analysis and frequency curves are tools used in hydrologic analysis to relate the magnitude of flows to their frequencies of occurrence. Often, the analysis is concerned with flow durations longer than a single day (e.g. 4-, 7- or 30-day). The frequency of occurrence for annual events is defined statistically by the probability of occurrence each year and is equal to the inverse of the recurrence interval. The recurrence interval is defined as the period of time in which one occurrence is expected or the inverse of the frequency of occurrence. For example, a flow with a 10 percent probability of occurrence has a frequency of 0.10 per year and a recurrence interval of 10 years. Frequency statistics for various duration flows are often denoted as (duration) Q (recurrence interval).

Thus the 7Q10 is defined as the lowest 7-day moving average flow that occurs on the average once in every ten years. Flow values derived from frequency analyses are most frequently plotted versus recurrence interval to produce frequency curves.

Low-flow frequency analysis may be made on the basis of either annual series or partial-duration series. Annual series are generally used unless frequencies of events longer than 12 months duration are required. Annual series frequency analysis is based on the minimum flow event of a given duration for each year of record. Frequency analysis may also be based on minimum flow events for shorter periods such as seasons or months. There are several methods used to calculate annual low flow frequency values. Two methods are graphical and mathematical.

Graphical Procedure

The procedure used with the graphical method is as follows:

1. Rank low flows. Moving average flows are calculated for given durations of x-days (e.g. 1-, 4-, 7- or 30-days). The minimum x-day flows for each year, season or month of record are ranked, with the lowest flow being ranked one.
2. Assign plotting positions. Plotting positions are assigned to each flow value using one of a number of available plotting position formulae. The formula most widely used and recommended is the common or Weibull plotting position (Riggs, 1974; McMahon, 1985) given as:

$$pp = \frac{m}{n + 1} = \frac{1}{T}$$

where pp = the plotting position and an estimate of the probability, P, of occurrence of an x-day flow that is less than or equal to a given ranked flow.

T = the estimate of the recurrence interval or the average period of time between years with an event less than or equal to the given x-day flow.

m = the rank of a given minimum annual x-day flow.

n = the number of years of daily flow data.

3. Plot points. Plot observed flows versus plotting position (probability of inverse of the recurrence interval) to show the magnitude and frequency of occurrence. Different types of probability paper may be used, including normal, log-normal or log-extreme value paper.
4. Fit equation. A smooth curve may be drawn through the points to fit the data and estimate the model error.

Figure 2.1 provides an example of graphical analysis of frequency statistic flows.

Mathematical Procedure

The mathematical procedure for determining nonexceedance probabilities consists of estimating the parameters for a theoretical distribution from a set of low flows and using the estimated distribution to generate flow magnitudes for given recurrence intervals. A number of different distributions have been discussed for use in low-flow analysis, including: normal, log-normal, Gamma, Pearson Type III, log-Pearson Type III, Kritsky-Menkel, Extreme Value Type 1 (Gumbel), or extreme Value Type III (Weibull) (McMahon, 1985).

Comparison of Graphical and Mathematical Procedures

Of the two methods discussed, the graphical method has been recommended in a number of papers (McMahon, 1985; ASCE Task Committee, 1980; Riggs, 1974)), particularly for determining flows of recurrence intervals less than n/3 years. The graphical method is considered by some to be superior to the

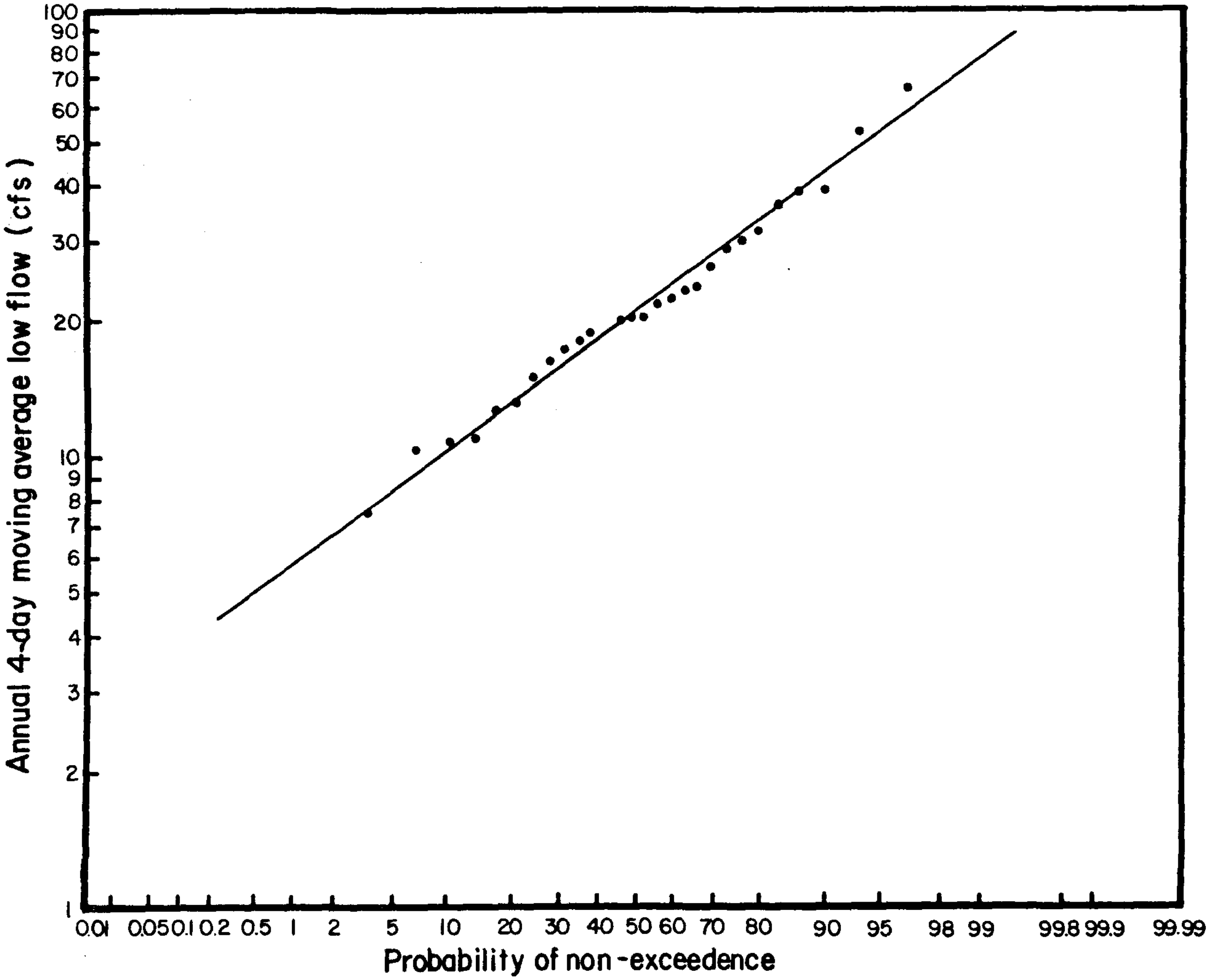


Figure 2.1 The graphical method of determining low flow frequency statistics at Littleton (1956-1985).

mathematical method for two reasons: 1) a graphical method requires no assumption as to the type or characteristics of a theoretical distribution and thus may better deal with a variety of low-flow regimes, 2) in some cases a purely statistical analysis may be misleading and provide less information than a graph (McMahon, 1985; Riggs, 1974). However, the mathematical method is more widely used for frequency analysis, probably because of its relative simplicity and consistency of results between different investigators.

Estimate of the Frequency Distribution

To identify an appropriate distribution function which would describe the distribution of low flows a three step procedure was followed. Four possible distributions were selected to be evaluated. They included the normal, the log-normal, the Pearson Type III, and the Log-Pearson Type III distributions. Appropriate transformations of the original low flows were selected which corresponded to the above mentioned distributions. Transformations used in this analysis were the logarithmic, the Wilson-Hilferty, and the Log-Wilson-Hilferty. To quantify how well the assumed distributions fit the low flow data, the Chi-square Goodness of Fit test and the Shapiro-Wilk test for normality were applied to both non-transformed and transformed low flows. The criteria used for selecting potential distributions was based on the relative scores of either passing or failing the Chi-square and the Shapiro-Wilk tests. A five percent level of significance was chosen for passing in the tests for normality. Distribution testing was done on both annual and monthly seven day low flows for the period of record at each station. Hence, for annual flows the entire record either passed or failed the tests for normality, i.e., a total score of one. However, when testing monthly low flows, the scores of each month passing or failing were recorded, i.e., total passing and failing equalled 12. The following is intended to be a brief description of the three transformations used in this study.

1) Logarithmic Transform:

The original low flows Y were transformed by

$$X = \log_e(Y)$$

This transformed series was then transformed into the standard form of the normal density function with a mean equal to zero and a variance equal to one. The calculation of the normal deviate is given by the equation:

$$Z = \frac{X - \bar{X}}{S(x)}$$

where X, $\bar{X}$, and S(x) were the log transformed flows, the mean log flow, and the standard deviation, respectively. If the logarithms of the flows were normally distributed, then the original flows themselves will have a lognormal distribution.

2) Wilson-Hilferty Transformation:

The original low flows Y are standardized by

$$X = \frac{Y - \bar{Y}}{S(y)}$$

where X, $\bar{Y}$, S(y) represent the Pearson Type III standard deviate, the mean low flow, and the standard deviation, respectively. The Wilson-Hilferty transformation was applied as follows (Matalas, 1967):

$$Z = \left\{ \frac{6}{G(x)} \left[\frac{G(x)X'}{2} + 1 \right]^{1/3} - 1 + \frac{G(x)}{6} \right\}$$

where Z is the normal standard deviate, G is the skewness coefficient, and X' is given by (McGinnis and Sammons, 1970)

$$X' = \begin{cases} \max[x, -2/G(x)] & \text{if } G(x) \geq 0 \\ \min[x, -2/G(x)] & \text{if } G(x) < 0 \end{cases}$$

The above form of the Wilson-Hilferty equation is valid when $G(x) \neq 0$. However, if $G(x) = 0$, then no transformation is necessary because $X = Z$.

3) Log-Wilson-Hilferty Transformation:

This transformation is essentially a combination of the logarithmic and Wilson-Hilferty transformations that were previously described. The original low flows were first logarithmically transformed by

$$W = \log_e (Y)$$

These transformed flows were then standardized to X, the Log-Pearson Type III standard deviate, using

$$X = \frac{W - \bar{W}}{S(w)}$$

where W, $\bar{W}$, and S(w) were the log flow, mean log flow, and the standard deviation of the log flow, respectively. The Wilson-Hilferty transformation was applied as given in item 2.

Goodness of Fit

To evaluate the level of agreement between an observed sample of low flows and an assumed theoretical distribution, a statistical goodness of fit test may be used (McMahon, 1985). The Chi-Square test is one standard test used for this purpose. The test is conducted by separating the range of possible low flow values into class intervals of equal probability based on the theoretical distribution. The intervals should be chosen so that the expected number of observations in each interval is five or more (Sanders, 1983). Actual low flow values are then split into each of the theoretically determined class intervals. The observed flows within each interval is compared with the number of theoretically expected number of flows. If there is a significant difference between the observed and expected values, then the initial hypothesis that the observed data fit the theoretical distribution is rejected.

Specifically, the Chi-Square statistic is computed as follows (Sanders, 1983):

$$X^2 = \sum_{i=1}^{K} \frac{(O_i - E_i)^2}{E_i}$$

where X^2 = Chi-Square statistic
E_i = expected value
O_i = observed value
K = number of class intervals

The computed Chi-Square statistic may be compared to a table value for the Chi-Square statistic, given a certain confidence level (usually 95 percent) and degrees of freedom (equal to the number of class intervals minus the number of estimated distribution parameters). If the computed value is greater than the table value, then the null hypothesis is rejected and the data appear not to be of the same distribution with a given level of confidence. For this study, the Chi-Square test was used to determine the goodness of fit of the data to the log-Pearson Type III Distribution.

One problem with the use of any goodness of fit test is that the test focuses on how well the entire distribution fits all of the data. This sort of test is not heavily influenced by the tails of a distribution and thus may not be able to accurately define the level of agreement specifically for minimum flows (McMahon, 1985). Two other criteria have been used to evaluate the applicability of various probability distributions to flow data. The first is to compare observed minimum flows with the lower limit of the theoretical distribution, and the second is to compare the relation between skewness and kurtosis of the observed to the theoretical distribution (Matalas, 1963).

The Shapiro-Wilk test was also used to test for normality in the non-transformed, and the three transformed low flows. This test has been shown to be an effective test for normality even with small sized samples (n<20) (Shapiro and Wilk, 1965). the maximum period of record in this study was 30 years, while two sites (Boulder and Fort Collins) covered 11 and 9 years, respectively. Therefore, the Shapiro-Wilk test meets the constraints of the flow records.

The test statistic, $\hat{W}_n$, is computed by

$$\hat{W}_n = \left[\sum_{i=1}^{n/2} (Z_{n-i+1} - X_i)\, A_{n-i+1}\right]^2 \Bigg/ (n-1)S^2$$

where Z are the ordered flows ($Z_1 < Z_2 < \ldots < Z_n$), A_{n-i+1} are coefficients given by Shapiro and Wilk (1965) and S^2 is the variance of the Z ordered flows. The null hypothesis of normality is accepted if the calculated $W_n >$ $W_{\alpha,\lambda}$, where $W_{\alpha,n}$ are tabulated percentage points given by Shapiro and Wilk (1965) for a given level of significance and sample size.

Log-Pearson Type III Distribution

For the purposes of this study, the mathematical method of defining frequency curves with the log-Pearson Type III distribution was chosen. The reason for this was primarily to maintain consistency with current, prevailing practices. The log-Pearson Type III distribution is widely used by various agencies for low-flow analysis including the USGS and the EPA (U.S. EPA, 1986; Petsch, 1979).

The Pearson Type III distribution is based on three statistical parameters - mean, standard deviation, and skewness coefficient. The distribution has a limited range in the left direction (zero) and unlimited in the right direction. This distribution is frequently fitted to the logs of flow and is thus called a log-Pearson Type III distribution. The most common way to fit this distribution is to calculate frequency factors for given recurrence intervals and then to use the following equation.

$$\log x = \bar{x}_{\log} + K(S_{\log})$$

where x = flow for a given recurrence interval T

$\bar{x}_{\log}$ = the mean of the logarithms of low flows

$S_{\log}$ = the standard deviation of the logarithms of low flows

K = a frequency factor, which is a function of the coefficient of skewness of the logarithms of low flows and the probability level and can commonly be found in tables (U. S. Interagency Advisory Committee, 1982).

One difficulty with low-flow analysis by the log-Pearson type III distribution or any other distribution which uses the skewness as a distribution parameter is the choice of a skew value to use. Generally, in flood flow analysis the skew used in the log-Pearson type III distribution is a combination of the regionalized skew and the station skew. Regionalized skews have not yet been developed for low flows in the state of Colorado. Consequently, station skews based on the historical record were used in the analysis. An alternative approach that has been recommended is to use zero for a skew value.

EXCURSION AND RUN LENGTH ANALYSIS

Analysis of daily flows below a given threshold level, or excursion analysis, was conducted for each site. For the purpose of this analysis, an excursion was defined as a single x-day flow below a given lower limit. The excursion analysis focused on 1-day low-flow events to quantify the number of days within each year with flows below a given level, and to examine the timing and lengths of low flow events. Both monthly and annual low flows were examined. The analysis was carried out by a computer program that ranked daily flows for each year from low to high, and listed the date of occurrence for each low flow. Flows below the given cutoff level (flow statistic) were totaled for each flow statistic. Excursions of duration longer than one-day were evaluated by a run length analysis. The run length of a low-flow event was defined as the number of consecutive days with flows below a given level. Run lengths were calculated and tallied for the low-flow events below a range of frequency statistic low flows at each of the sites. The number of excursions occurring within a given low-flow event can be calculated as the run length of the event divided by the duration of the excursion. For example, the number of 30-day excursions occurring in a run length of 35 days would be 35/30 or 1.17 excursions.

EPA BIOLOGICALLY-BASED DESIGN FLOW CALCULATION

A biologically-based method for determining design flows was recently developed by the Office of Research and Development of the U.S. E.P.A. The biologically-based method is an empirical, distribution-free approach that utilizes historical records of daily flows. The method is empirical; because it is based on the actual flow record, rather than on flows predicted by a statistical distribution. Design flows for both acute and chronic levels of aquatic life protection are calculated with this method.

Design Flow Criteria

The design flow calculated with the biologically-based method is defined as the highest flow of a given duration that will not cause a given instream concentration to be exceeded with greater frequency than is allowable. The biological rationale for this new EPA method is found in 1985 EPA guidelines for deriving national water quality criteria (Stephan, 1985). The current national criteria are expressed as two levels, acute and chronic rather than the traditional one level, to reflect actual toxicological conditions more accurately as described earlier. Three major factors are considered in design flow criteria: frequency (inverse of the average recurrence interval), intensity (concentration), and duration (length of averaging period).

The allowable frequency of low-flow events used by the U.S. EPA is once every three years. The concentrations used are the Criterion Maximum Concentration for acute flows and the Criterion Continuous Concentration for chronic flows. Durations are 1-day for acute flows and 4-day or longer for chronic flows. As mentioned previously, longer durations may be justified for relatively stable flow and water quality conditions. The U.S. EPA has used a low coefficient of variation (C_v) of daily flows as an indicator of stability. Generally, a C_v of one or less is considered adequate justification by the EPA.

Methods

The general approach of the biologically-based technique is to look at the number of low-flow excursions (low flows below a lower limit) that have occurred in the past to gain an understanding of how many excursions are likely to occur in the future. A daily flow record is split into low-flow periods and low flow excursions are counted for various low flow limits.

The flow that is chosen for the design flow is the maximum flow that results in no more than the allowed number of excursions for the entire period of record, or no more than one excursion every three years.

Low-flow periods used for analysis by the U.S. EPA biologically-based method are 120-day periods, rather than the more traditional annual period. According to the U.S. EPA, low flows are expected to occur in a certain pattern grouped within a 120-day low flow period followed by a 120-day period of few, if any, low flows (U.S. EPA, 1986). Each low-flow period begins with a low-flow excursion (a low flow below a lower limit or design flow) and lasts exactly 120 days. Depending on the pattern of low-flow excursions, the number of days between low-flow periods may vary.

Within each 120 day low-flow period, there may be one or more low-flow excursion events. An excursion event is defined as a sequence of consecutive days where each day belongs to an x-day average flow that is below the design flow (U.S. EPA, 1986). For example, if three 4-day moving averages of a consecutive six day period are less than the design flow, then those six days belong to a low-flow excursion event. The number of excursions in an excursion period is calculated as the total number of days in the period divided by the duration (e.g. one day for the CMC and four days for the CCC). The maximum number of excursions to be counted for any given low-flow period is five. Given an allowable frequency of one excursion every three years, this provides for no more than 15 years, on the average, for ecosystems to recover from severe stress caused by a drought.

Procedure

The biologically-based design flow calculations is an iterative convergence procedure that consists of five basic parts (U.S. EPA, 1986). The parts are:

1. Determination of the allowed number of excursions, the number that will produce an average of no more than one excursion every three years, given by the equation:

   (allowed excursions) = (number of years of record)/(3)

2. Calculation of x-day (1-day for CMC, 4-day for CCC) running averages from the record of daily flows.
3. Calculation of the total number of excursions of a specified flow for a given flow record.
4. Determination of initial lower and upper limits on the design flow with the corresponding number of excursions from Part 3, and an initial trial flow.
5. Calculation of the design flow by successive iterations using the method of false position.
6. Note - In certain cases, values other than the standard ones given for durations (1-day or 4-day) or frequency (once in three years) may be used to calculate special user-defined flows.

The above procedure is carried out by computer program (EPA's DFLOW or DESCON) used in conjunction with direct access to STORET daily flow record files. For the purposes of this study, an IBM PC version of DFLOW was converted for use on the Cyber 205 and was used in conjunction with data files with USGS daily flow records.

DATA ASSUMPTIONS AND ERRORS IN LOW-FLOW ANALYSIS

Certain assumptions about flow data must be achieved for most statistical analyses to be valid. The assumptions are as follows: 1) the record is a representative time sample, 2) flow events are random and independent, and 3) the record is homogeneous (U.S. Interagency Advisory

Committee, 1982). The violation of these assumptions may produce statistical results that are less reliable or even invalid, depending on the degree of violation. One of the first steps in low flow analysis should be to check the adequacy of the flow data and the applicability of specific statistical analyses.

Representative Time Sample

A representative time sample requires that the flow record is complete and is long enough to include the full range of a characteristic flow regime. An adequate length of record has been recommended as 30 years or more (McMahon, 1985).

Random and Independent Events

Statistical analysis is usually based on a subset of measurements of the entire population, called a sample. For a sample of flows to be random, each member of the population (or each flow for a given day) must have an equal and independent chance of being selected. Independent events require that the occurrence or nonoccurrence of one event has no bearing on the chance that the other will occur.

Daily streamflows form a time series, a sequence of events arranged in order of occurrence (Riggs, 1977). Usually these flows are positively correlated, meaning that a low flow one day is followed by another low flow on the next day. Serial correlation tests provide an indication of the degree of correlation of flows. Annual minimum low flows may be considered to be a sample of random and independent events (U.S. Interagency Advisory Committee, 1982). Annual events are generally not as highly correlated as daily events, although long-term persistence of drought may occur and upset this assumption. Monthly minimum flows may exhibit a higher degree of serial correlation than annual values and thus may not strictly be considered random and independent.

Homogeneous Record

Homogeneity of a flow record implies that data are taken from the same population, or that the flow regime has remained relatively constant over the entire period of record. Non-homogeneity may often result from man-made developments or by the movement of a gaging station. It is recommended that only records that represent relatively constant watershed conditions be used for frequency analysis (U.S. Interagency Advisory Committee, 1982; Searcy, 1959).

A variety of techniques are available to test homogeneity of flow records. Double-mass analysis evidences non-homogeneities as changes of slope in the plot of massed flow at the point of interest against massed flow at an unaffected gage or gages in the general vicinity or against massed precipitation (Pitman, 1978). Other ways to detect non-homogeneities include examination of plots of annual 7-day low flows versus time, or comparison of annual 7-day low flows at the point of interest to a reference flow record (Riggs, 1976). One problem with these techniques is the possibility that the timing of wet and dry periods may introduce bias (Pitman, 1978). For example, if a flow record begins with a dry period (lower than average flows) and ends with a wet period (higher than average flows), then there will be a bias toward a trend of increasing flows.

Another approach to detecting non-homogeneity of a flow record is to split the record into two groups defined by a suspected change in the flow regime, and to test for differences between sample statistics such as the variances and between the means of each group. The groups should be chosen so as to reflect a suspected change in the flow regime, such as that resulting from the construction of a dam upstream from the gage. If both groups have the same variance and the same mean, then there is sufficient justification that the period of record may be said to be homogeneous.

Differences between the variances of two different segments of a given flow record may be tested using a variance ratio test, or F test (Zar, 1974). The F statistic is calculated as follows:

$$F = \frac{(S_1)^2}{(S_2)^2}$$

where F = F statistic

$(S_1)^2$ and $(S_2)^2$ = variances for samples 1 and 2

The calculated F-statistic may be compared to a table of values for a given level of significance and degrees of freedom (a function of the number of data) for each sample. If the calculated value is less than the table value, then the hypothesis that the two variances are not significantly different is accepted. The variance ratio test assumes that the populations being sampled are normally distributed, and may be adversely affected by nonnormal populations. Data transformations (such as a log transformation) may be made to make skewed flow data more normally distributed.

Differences in the means of two samples may be detected with a two-sample t-test (Zar, 1974). A t statistic is calculated as follows:

$$t = \frac{\bar{x}_1 - \bar{x}_2}{S_{(\bar{x}_1 - \bar{x}_2)}}$$

where $\bar{x}_1 - \bar{x}_2$ = the difference between the two means

$S_{(\bar{x}_1 - \bar{x}_2)}$ = the standard error of the difference between the means

If the calculated t statistic is less than a comparable table value, then the two means are not significantly different as defined by this statistical test. The assumptions required for the t test to be valid are for the samples to have equal variances, to be random, and to be derived from normal populations. In many cases, these assumptions are not always correct. However, the t test has been shown to be robust enough to remain valid even with violations of these assumptions. In other words, the assumption of normality is not absolutely necessary (Zar, 1974).

In this study, homogeneity of all flow records was analyzed first by looking at plots of annual low flow statistics versus time. For records where a distinct change in flow regime was suspected, F and t tests were conducted. Homogeneity testing using these tests was conducted at the Littleton and Englewood sites. The operation of Chatfield reservoir on the South Platte River beginning on May 29, 1975 was suspected to produce a detectable change in the flow regimes at these sites which are located just downstream. The log transformed values of annual low flows at Littleton and Englewood for the period 1956-1975 were tested against those for 1976-1985. The Statistical Package for the Social Sciences (SPSS, Nie, et al., 1975) was used on the Cyber mainframe computer at CSU to complete this analysis. Values for the two-tail probability were calculated and compared to a reference level of 0.05. Values greater than 0.05 were considered to show no significant difference in variances or means.

Reliability of Low-Flow Analysis

Errors may be introduced to low-flow analysis from a number of different sources to produce estimates which may differ from the true values. The degree of reliability of flow estimates depends on the quality of the flow record and also on the applicability of various statistical analyses.

The quality of a flow record for use in low-flow analysis may be affected by two major types of errors, measurement errors and rating curve errors (McMahon, 1985). Measurement errors may be either systematic, due to instruments of measurement methods, or accidental, due to observers. Rating curve errors may result from inaccurate rating curves based on insufficient low flow discharge measurements, or from changing stage-discharge relations due to shifting controls. Errors are generally considered a random process with a relatively small variance (U.S. Interagency Advisory Committee, 1982).

Errors in statistical analysis of low flows can result from a number of sources. Whenever necessary statistical assumptions are violated, error is introduced. The magnitude of the error will be related to the degree of violation of given assumptions. Fitting a given flow record to some sort of underlying probability distribution to predict frequency statistic flows may also introduce errors. Parameter estimates may include errors, and a distribution may not always provide a good fit and may make inaccurate predictions of low flows.

CHAPTER 3 - FLOW DATA ANALYSIS FOR COLORADO STREAMS

SITE DESCRIPTIONS

Flow data at eight sites on four different rivers in Colorado including the South Platte River, Boulder Creek, St. Vrain Creek, and the Cache la Poudre River were analyzed in this study. Flow analysis of the South Platte River was made at three sites - Littleton and Englewood in segment 14, and Henderson in segment 15. Boulder Creek analysis was made just above the City of Boulder wastewater treatment facility near 75th Street. Flows of the Saint Vrain Creek were analyzed at Lyons, Longmont, and Platteville. The Cache la Poudre River was analyzed at Lincoln Street in Fort Collins. Analysis of theoretical effluent limits based on various design flows was made for four different wastewater treatment facilities administered by: the Cities of Littleton and Englewood, the City of Boulder, the City of Longmont, and the City of Fort Collins. Specific descriptions of each of the sites follow below.

South Platte River (segment 14)

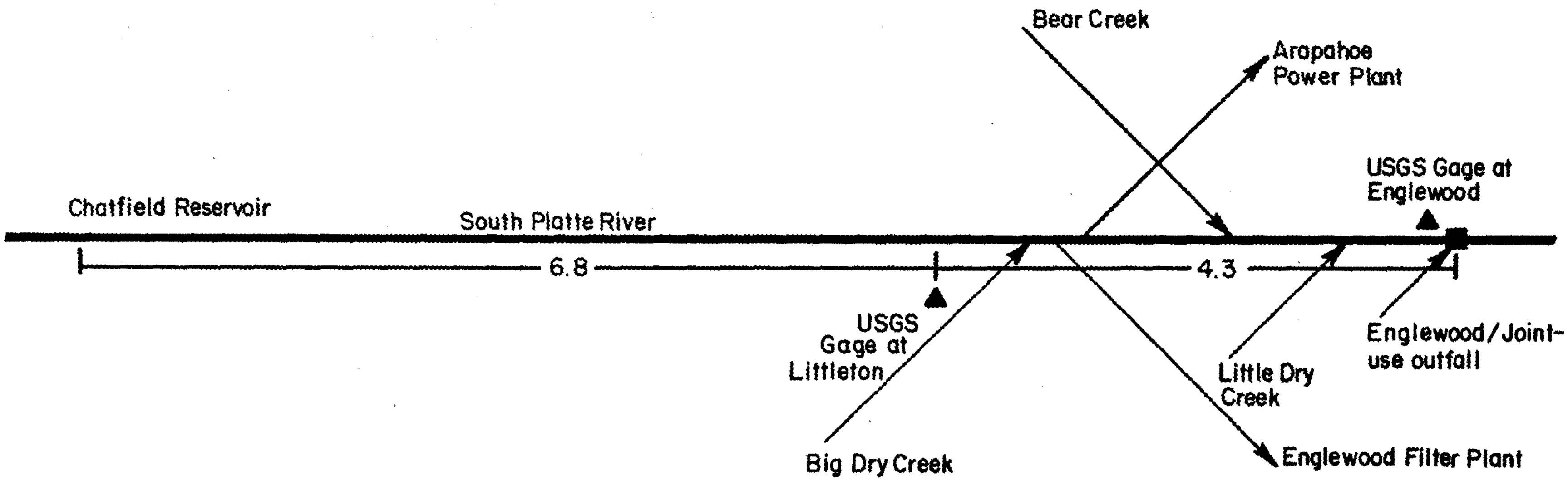
The South Platte River is classified for the following uses in segment 14: class II recreation, class I warm-water aquatic life, water supply, and agriculture. Chatfield dam and reservoir began regulation of the river upstream of Littleton and Englewood on May 29, 1975. The U.S. Geological

Survey (USGS) gage at Littleton (06710000) has a drainage area of approximately 3069 square miles and a period of record from 1941 to current. The period of record analyzed at Littleton included the years 1955-1985. The USGS gage at Englewood (06711565), located about four miles downstream of Littleton, was recently installed and has a record from 1982 to current. A water balance technique was used to extend the flow record at Englewood by using the record at Littleton and accounting for gains and losses to the river between Littleton and Englewood. Three major tributaries enter the South Platte River downstream from Littleton and upstream from Englewood. Bear Creek is gaged (USGS at Sheridan 06711500) and has a drainage area of 260 square miles. The other two creeks are not gaged. Two major diversions are made from the river between Littleton and Englewood. Figure 3.1 gives the location of these features.

The wastewater treatment facility of the Cities of Littleton and Englewood consists of two plants that discharge into the South Platte at a single point. The Joint Use Plant has a rated design capacity of 27 MGD (million gallons per day), and uses an activated sludge process with chlorination and dechlorination. The Englewood plant uses a trickling filter, chlorination, and dechlorination and is rated for eight MGD. Total discharge for both plants based on the actual record for 1982-1985 averaged 22 MGD on an annual basis and varied from 19.6 to 24.1 MGD on a monthly basis.

South Platte River (segment 15)

Segment 15 of the South Platte River is classified for the same uses as segment 14, except that it is class II warm-water aquatic life, rather than class I. The USGS gage at Henderson (06720500) has a long record, from 1895



NOTE= Not to scale, distances are approximate values given in miles.

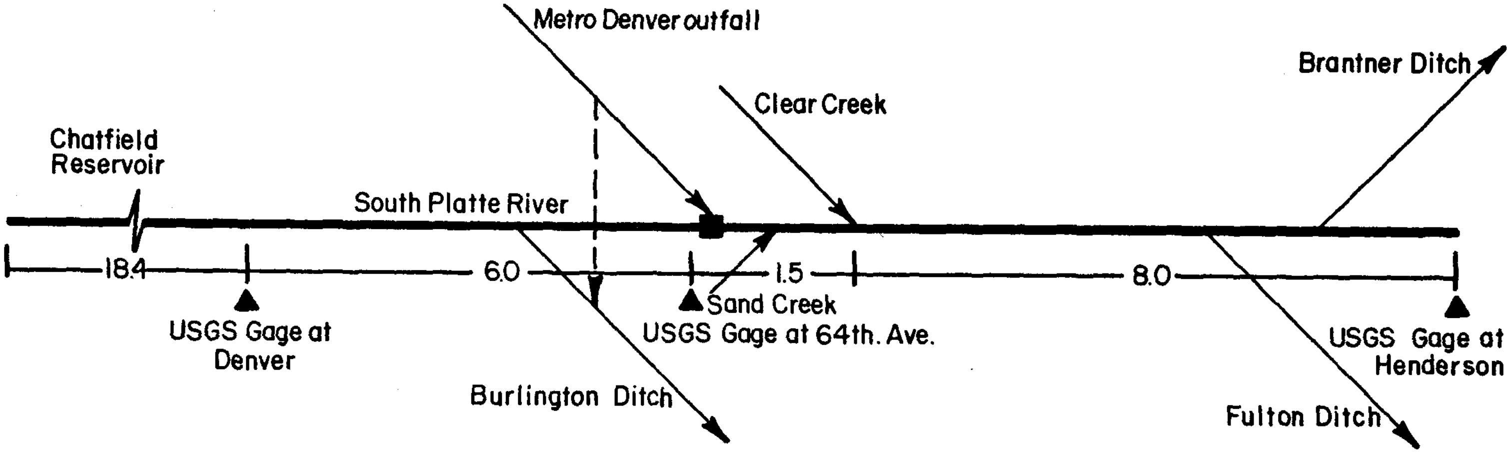
Figure 3.1 Straight-line diagram for the South Platte River (segment 14).

to current, and drains 4713 square miles. Flow data for the period 1955-1985 was analyzed at Henderson. The Denver gage at 64th Avenue (06714215), nine miles upstream from Henderson, drains 3829 square miles and has a very short record, 1982 to current. The prediction of flows at 64th Avenue is complicated by a number of factors. The Burlington Ditch diverts water from the South Platte River just upstream from 64th Avenue at an average of about 200 cfs. Water that is diverted at the Burlington headgate in excess of the allocated right is returned to the South Platte River via Sand Creek, just downstream from the gage at 64th Avenue. Major tributaries include Sand Creek (ungaged) and Clear Creek (USGS 06720000) which flow into the South Platte River downstream of 64th Avenue. Two major ditches divert flows from the river below 64th Avenue and upstream from Henderson. Figure 3.2 shows the locations of these features.

The wastewater treatment facility for Metro Denver (MDSDD) consists of two treatment complexes. The north complex uses a conventional activated sludge process and the south complex uses a high purity oxygen process. The two plants together are rated for 185 MGD design capacity flow. Average annual flows based on actual records for 1981 to 1985 were about 140 MGD, while monthly flows ranged from 126 to 157 MGD. Discharge from the Metro Denver sewage plant may be routed to two different locations - the South Platte River or the Burlington Ditch, depending on water right requirements.

Boulder Creek

The segment of Boulder Creek that was analyzed in this study is classified for the following uses: class I recreation, class I warm water aquatic life, agriculture, and water supply. Flows in Boulder Creek were analyzed at a point just upstream from the 75th Street Bridge and above the outfall from the City of Boulder wastewater treatment facility. There is



NOTE = Not to scale, distances are approximate values
given in miles.

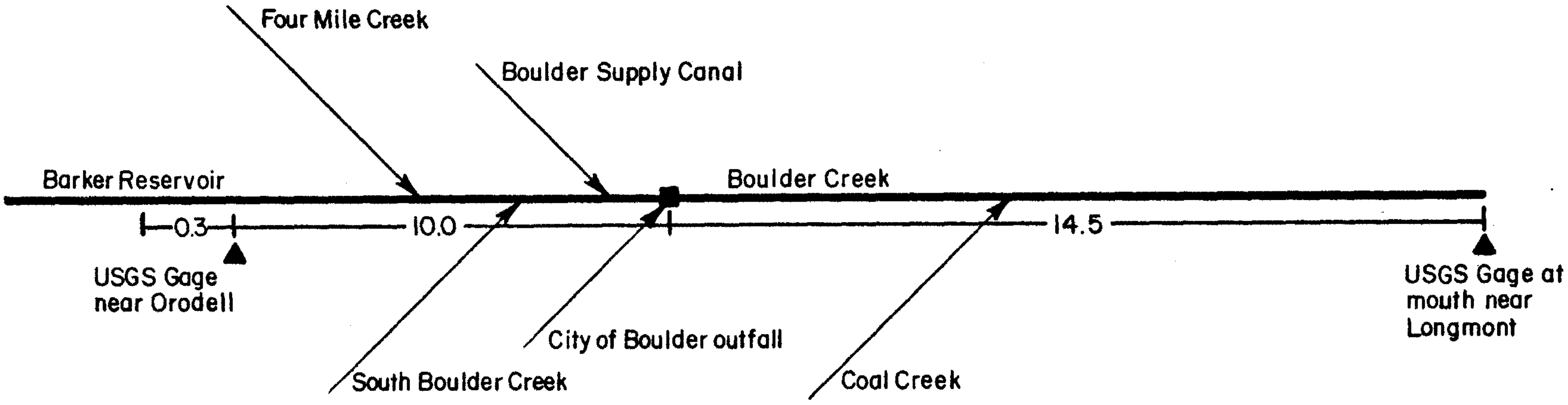
Figure 3.2 Straight-line diagram for the South Platte River (segment 15).

currently no USGS gage at this site, although future plans call for a gage at 75th Street. The closest gage is approximately 10 miles upstream, located near Orodell (06727000). A number of major diversions and inflows occur between this gage and the 75th Street location. The nearest downstream gage is located at the mouth of the creek near Longmont (06730500) approximately 14.5 miles away. These features are illustrated in Figure 3.3.

The wastewater treatment facility of the City of Boulder is a trickling filter type with a rated capacity of 15.6 MGD. Average annual flows based on actual records for 1983 to 1985 were approximately 15.3 MGD with monthly averages ranging from 13.1 to 16.9 MGD.

St. Vrain Creek

Use classifications for St. Vrain Creek in the area analyzed in this study are as follows: class II recreation, and class I warm-water aquatic life. Three sites at streamflow-gaging stations along the St. Vrain were analyzed. The first site is at Lyone (USGS gage 06724000), with a drainage area of 212 square miles and a period of record beginning in 1895. Flows at Lyons were analyzed for the period 1955-1985. Approximately 16 miles downstream is the next site, the USGS gage below Longmont (06725450). More than 30 diversions for irrigation water take water from the creek between Lyons and Longmont. The St. Vrain drains an area of 424 square miles at Longmont gage which has a seven year period of record which includes 1977-1982 and 1985. The gage below Longmont is located approximately four miles downstream from the outfall from the City of Longmont wastewater treatment facility. Major tributary inflows include Spring Gulch and South Dry Creek which enter the St. Vrain between the gage and the outfall. The third site on the St. Vrain is Platteville (USGS gage 06731000). This gage has a



NOTE = Not to scale, distances are approximate values given in miles.

Figure 3.3 Straight-line diagram for Boulder Creek.

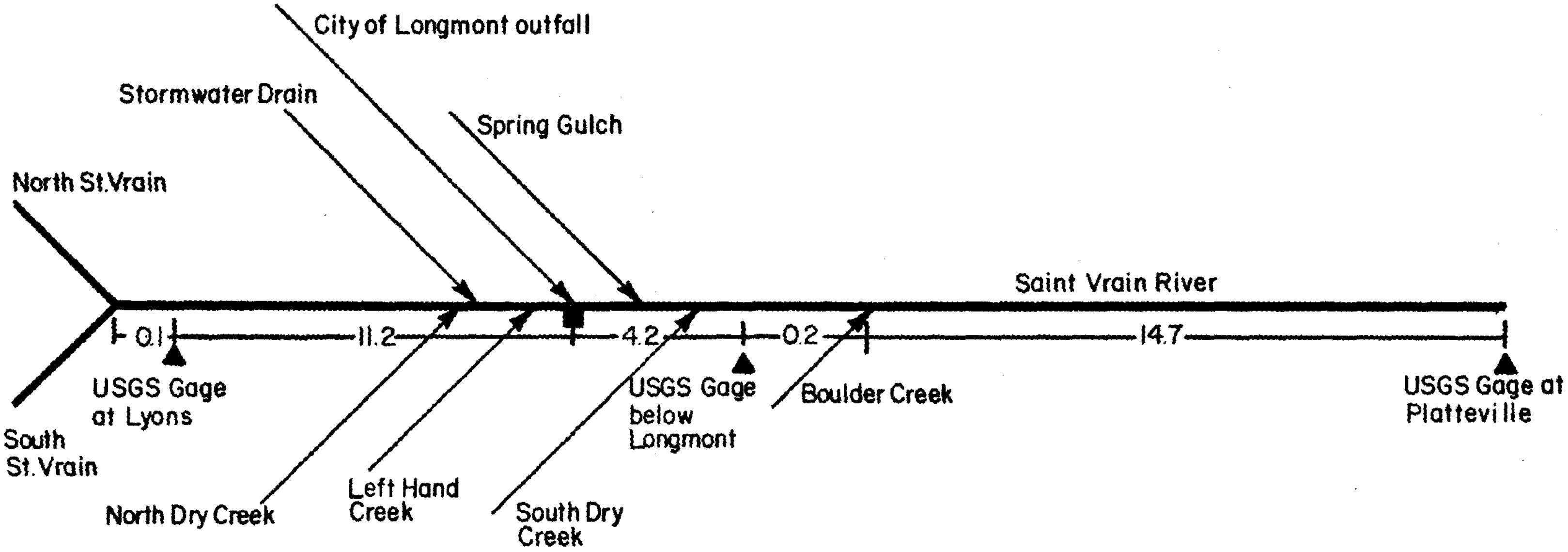
drainage area of 976 square miles and a period of record from 1927 to current. Flows from 1955-1985 were analyzed at Platteville. Figure 3.4 shows the features described here.

The wastewater treatment facility for the City of Longmont is a trickling filter plant. The current rated design capacity for the plant is 11.55 MGD.

Cache la Poudre River

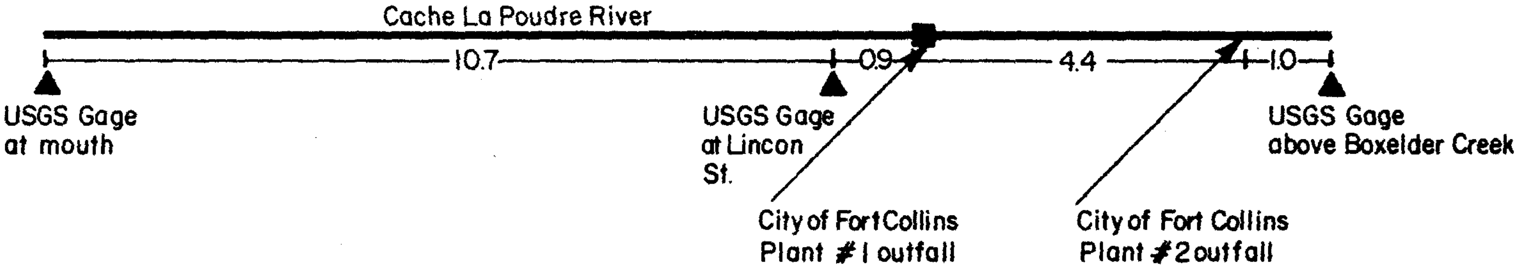
Flow analysis on the Cache la Poudre River was limited to one site, Fort Collins. The river in that area is classified by use for class II recreation, class II warm-water aquatic life, and agriculture. The specific site analyzed was the USGS gage at Lincoln Stree in Fort Collins (06752260) which has a drainage area of 1127 square miles and a 10 year record from 1976-1985. A correlation of the flows at Lincoln Street with flows at another site on the Poudre with a longer record was not feasible because of the high level of regulation of the river. The gage at Lincoln Street is located less than one mile upstream from the City of Fort Collins wastewater treatment plant number one. Figure 3.5 illustrates the major features of the Cache la Poudre River important to this study.

The City of Fort Collins has two treatment facilities, number one and number two. The plant in proximity to the Lincoln Street gage, number one, was used for effluent analysis in this study. Fort Collins plant number one is a trickling filter plant with chlorine disinfection and is rated for seven MGD flow. Actual annual flows for the period 1982-1985 averaged 4.7 MGD with monthly averages ranging from 4.0 to 5.6 MGD.



NOTE = Not to scale, distances are approximate values given in miles.

Figure 3.4 Straight-line diagram for the Saint Vrain River.



NOTE = Not to scale, distances are approximate values given in miles.

Figure 3.5 Straight-line diagram for the Cache La Poudre River.

FLOW DATA RECORDS

The data base used for flow analysis in this study consisted of USGS daily records for five of the eight sites (Littleton, Henderson, Lyons, Platteville, Fort Collins). Two of the other sites (Englewood and Longmont) had periods of record too short to analyze and a third site (Boulder) was ungaged. Flow records of appropriate length for these three sites were developed using three different techniques. The techniques included a water balance used at Englewood, a streamflow model used at Boulder, and regression analysis used at Longmont. These techniques will be discussed in detail.

USGS Gages

Flow data collected at the USGS stations used in this study consist of mean daily flows. The daily averages are based on stage height measurements that are taken on a continuous basis or at 5, 15, 30 or 60-minute intervals. Stage height measurements are converted into discharges through the use of rating tables, which are prepared by the USGS from stage-discharge relation curves. Correction factors may be applied to discharges by using the shifting-control method to account for changes in stage-discharge relations over time (Duncan, 1984).

USGS stream-gaging stations are checked on a regular basis to see that equipment is functioning correctly and that readings are accurate. Generally, this occurs once or twice a month. In a number of cases, the USGS cooperates with another agency, such as the Colorado State Department of Natural Resources (DNR), to administer a gage. At a cooperatively administered gage the DNR is responsible to take gage readings and the USGS reviews and publishes the flow record.

The accuracy of streamflow data records has been rated by the USGS at each of the gages they administer. The ratings include four degrees of accuracy. "Excellent" means that about 95 percent of the daily discharges are within 5 percent of the true value; "good" means within 10 percent, "fair" means within 15 percent, and "poor" means greater than 15 percent (Duncan, 1984). Daily mean discharge is given to the nearest hundredth of a cfs for discharges less than 1.0 cfs, to the nearest tenth for discharges of 1-10 cfs and to the nearest whole for discharges of 10-1000 cfs. All of the gages used in this study were rated "good" by the USGS, except for the gage at Littleton, which is rated "fair" during the winter period, and the gage at Fort Collins, which is rated "poor" for certain periods with no gage-height record. It should be noted that these gage ratings apply to the daily flow record as a whole. Typically, extreme low and high flows are more difficult to measure accurately than average flows. As a result, low-flow gage data probably are less accurate than gage ratings would indicate.

Englewood Flow Record

A daily reconstructed flow record for the USGS station at Englewood (06711565) was developed for the period 1955-1985 using a water balance procedure. Another valid approach at this site would be to use regression analysis to correlate flows at Englewood to flows at Littleton. The water balance method was used here for illustrative purposes since regression analysis was applied at another site. Flows were routed from the USGS station at Littleton (06710000) approximately four miles downstream to Englewood by accounting for six factors which affect flow in the South Platte River (Figure 3.1). These factors include four sources - Bear Creek, Big Dry Creek, Little Dry Creek, and groundwater inflow; and two losses - Englewood Filter Plant and Arapahoe Power Plant.

Daily flow records were not available for any of the above listed factors except for Bear Creek (USGS station 06711500). Flows for Big and Little Dry Creek were based on regressions using four data points for each creek and on average monthly flows at Littleton.

Data on groundwater recharge in the South Platte Basin are limited to one section of a study made on segment 14 of the South Platte River (Lewis, 1986). However, groundwater plays an important role in the low-flow hydrology of the river and should not be ignored. The above-mentioned study was used as a basis for assuming that the South Platte receives an average of five cfs per mile for the four miles between Littleton and Englewood. Although this assumption is without a strong basis, it does provide an initial estimate of groundwater flows until further studies can be conducted.

Diversion records for the Englewood Filter Plant and Arapahoe Power Plant were based on monthly averages for the years 1975-1985. It was assumed that flows for both diversions are relatively constant from day to day throughout a given month. With this assumption, daily flow values within a given month were assigned the average monthly flow for the entire month. A second assumption was made that diversion flows for the period 1975-1985 are fairly representative of flows which might occur in the near future. To achieve a longer period of record that is consistent with existing conditions, monthly average diversion flows were used to predict daily flows for the period 1955-1974.

The goodness of fit to actual data of the daily flow record predicted by a water balance procedure at Englewood was evaluated in two ways - by using F and t-tests, and by comparing summary statistics for actual and predicted flows for 1982-1985. The results of the F test at a 5 percent level of significance showed no significant difference in variances. The t-test showed no significant difference in means.

A second evaluation of the goodness of fit is given in the comparison of summary statistics calculated for both sets of daily flow data. the results are listed in Table 3.1. Both the mean and median are higher for the water balance record as is the minimum flow. The standard deviation is somewhat higher for the water balance record meaning that the flows vary more from the mean. Kurtosis and skewness values are quite close, which indicates that the distribution shapes are quite similar. The 95 percent confidence intervals overlap one another, with the water balance record being slightly higher.

In general, the flow record derived from the water balance method seems to represent actual flows fairly well, though there are some difficulties. The water balance may produce flows greater than the actual, particularly lower flows, as indicated by the summary statistics. The addition of a constant groundwater recharge factor to a stochastic process may have caused the predicted low flows to be slightly higher than actual flows. Flow predictions for Big Dry Creek and Little Dry Creek were made on a very limited data base and may also introduce errors into the analysis.

Assumptions made about diversion data may have caused inaccuracies as well. The assumption of consistent flows from day to day throughout a given month may be a reasonable one for the power plant which consumes approximately one cfs, but may be less reasonable for the filter plant which diverts average monthly flows ranging from 7-21 cfs. The second assumption, that flows for the period 1975-1985 are representative may also be inaccurate, although flows do seem to vary less over the years than from month to month.

Table 3.1. Comparison of actual flow record to flow record derived from water balance at Englewood for the period 1982-1985 (973 observations).

Summary statistics*	Englewood USGS station	Englewood Water balance
Mean	754	792
Median	418	425
Std dev	780	849
Minimum	28	45
Maximum	3910	3716
95% Confidence Interval	705 to 803	738 to 845
Skewness	1.4	1.5
Kurtosis	1.2	1.2

* Units = cfs (except skewness and kurtosis)

Even with all the above-mentioned sources of inaccuracy there appears to be no significant difference in variances or means of the monthly 7-day low flows and summary statistics of daily flows are relatively consistent. The accuracy of the flow data set is sufficient for the needs of this study, which is focused on a comparison of various design flows and not on defining flows without a gaging record at given points. However, further work on groundwater and other ungaged factors could be done to refine the accuracy of daily flow estimates at Englewood.

Boulder Flow Record

The flow record at Boulder was estimated using a model of daily flows that was run for a 12-year period from 1959 to 1970. The model was developed by a consultant for the City of Boulder (Harding, 1986). Diversion records, USGS gages and various methods to estimate ungaged flows were incorporated into the model. The 12-year daily flow record at Boulder includes 364 values for each year with the 365th value dropped. Leap years are the same as all other years with no value for February 29. A more complete description of the model is included in a memo given in Appendix A.

Longmont Flow Record

Flows at Longmont were estimated on the basis of multiple regression analyses. The analyses were made with the Statistical Package for the Social Sciences (SPSS) (Nie, et al., 1975) on the CSU Cyber mainframe computer. Flow data at the USGS station below Longmont for the years 1977-1982 and 1985 were used along with data from USGS stations at Lyons and Platteville for the same period to define the regression equations.

Three different approaches were used for the regression analysis at Longmont. The first regression was based on daily flows. Multiple regression analysis was made to regress daily low flows at Longmont with flows at Lyons and Platteville. The flows evaluated were restricted to low flows, defined by a flow occurring on a day when the flow at Lyons was less than 100 cfs. An equation was developed for flows at Longmont and was used to extend seven years of actual data at Longmont to a 31-year record for 1955-1985. The equation produced is as follows:

$$\text{Longmont} = (0.32\ \text{Platteville}) + (0.53\ \text{Lyons}) - 4.47.$$

The coefficient of variation (r^2 value) for the equation is equal to 0.77, which is indicative of an acceptable fit of the data to the equation. A second measure of the accuracy of the predicted data is given by a comparison of summary statistics calculated for predicted and actual records for a seven-year period (Table 3.2). From these statistics, it appears that the predicted values based on a regression of daily flows are reasonably accurate. The medians of the two sets of data are quite close, though the predicted mean is higher than the actual. The predicted standard deviation is higher than the actual, indicating greater variability in predicted than actual values. The ranges of the two data sets overlap, but the minimum and maximum of the predicted values are both lower than actual. It could be that the low values of the predicted data record are slightly lower than the actual. This would tend to produce lower than actual frequency statistic low flows.

One weakness of a regression of daily flows is that the assumption of independent events is violated. This violation may limit the accuracy of the analysis. In addition, the assumption of normality of the data may not be met.

A second regression at Longmont was similar to the first except that the daily flows were transformed to log values before an equation was developed and all the data were used. This transformation was made in an

Table 3.2. Comparison of actual flow record to flow records based on two different regressions of daily flows at Longmont for the period 1977-1982,1985 (1095 observations).

Summary statistics*	USGS station	Regression of daily flows	Regression of log-transformed daily flows
Mean	72	88	111
Median	51	52	62
Std dev	78	97	157
Minimum	24	19	15
Maximum	663	584	1634
95% Confidence Interval	55 to 89	67 to 109	105 to 117
Skewness	5.6	3.2	4.8
Kurtosis	40.4	11.9	29.9

* Units = cfs (except skewness and kurtosis)

effort to normalize the data. The equation from this analysis is as follows.

$$\log \text{Longmont} = (0.7518 \log \text{Platteville}) + (0.2418 \log \text{Lyons}) - 0.2171.$$

The coefficient of variation for the equation is 0.90. Summary statistics on the predicted flows based on this regression of log-transformed values are given in Table 3.2. Even though the r^2 value is higher for this second equation, the statistics show that it provides less accurate predicted values than the first regression. The values are much more variable, and appear to be generally higher than actual values.

A third approach at Longmont involved regression analysis on log-transformations of specific monthly or annual frequency statistic low flows. Six separate regression equations were developed for monthly 1-, 4- and 7-day flows and for annual 4-, 7- and 30-day flows as given in Table 3.3. No equation was developed for annual 1-day flows since they were not significantly correlated. The range of coefficients of determination (r^2values) for all of the equations was from 0.80 to 0.91. These values indicate that each of the equations should be able to predict monthly or annual low flows at Longmont with reasonable accuracy.

One strength of this third approach to regression analysis at Longmont is that the assumption of independence of events is more valid with monthly or annual flows than with daily flows. The log-transformation should make the assumption of normality more valid as well. A weakness of the approach is the limited number of data points to correlate for regression equations (7 for annual flows, 84 for monthly). Another disadvantage is that since a daily flow record is not developed, certain analyses like the biologically-based calculation of design flows and excursion analysis are not possible.

Table 3.3. Regression equations for annual and monthly low flow frequency statistics at Longmont.

Low flows	Equation*	Coefficient of determination
Annual:		
4-day	$Y = 0.228 + 0.671 X$	0.88
7-day	$Y = 0.133 + 0.726 X$	0.89
30-day	$Y = -0.49 + 1.031 X$	0.91
Monthly:		
1-day	$Y = 0.016 + 0.691 X + 0.185 Z$	0.88
4-day	$Y = 0.427 + 0.459 X + 0.155 Z$	0.80
7-day	$Y = -0.057 + 0.686 X + 0.232 Z$	0.90

* Definition of variables in equations:
Y = log (Longmont moving average flow)
X = log (Platteville moving average flow)
Z = log (Lyons moving average flow)

The two regression equations for daily flows at Longmont were used to generate a daily flow record for the period 1955-1976 and 1983-1984, thus extending the actual record to cover a 30-year period. These generated flow data records were treated just as a record from a USGS gage in the remainder of the analysis. Monthly and annual low flows for each year of record generated from the six equations which were developed in the third approach to regression analysis. Frequency statistic flows were calculated from this set of data using Log-Pearson Type III analysis.

The results of the analysis by each of the three regression methods are given in tables A1.11-A1.16 and figures A1.16-A1.18 for annual flows and tables A2.3-A2.5 and A2.24-A2.32 for monthly flows. A comparison of the values indicate that the two regressions of daily flows produce frequency statistic flows that are very similar. The flows calculated with the set of six different regression equations do not seem to be as valid as either of the other two results. This is well evidenced by the odd pattern of the annual frequency curves in Figure A1.18 and the inconsistency of values in the tables of annual and monthly flows (e.g. 4-day flows frequently smaller than 1-day flows). These inconsistencies can probably be attributed to the fact that a series of regression equations, each with its own errors, was used rather than a single equation.

It appears, that at Longmont the most valid approach to the regression is a simple linear regression of daily flows below a given level. This result may not hold true at other sites, however. Each of the methods may be valid, but should be checked for appropriateness in a specific instance.

Homogeneity of the Flow Record

Many of the streams along the Front Range have been heavily influenced by man's activities and may exhibit changes in the low-flow regime or non-homogeneities, as a result. Two approaches were used in this study to identify changes in low-flow characteristics - plots of annual 7-day low flows versus time, (Figure 3.6 and A1.1-A1.8) and F and t-testing for changes in mean and variance. The plots show a variety of patterns in annual low flows. Some sites seem to exhibit a trend, while others appear to have cycles in low flows. The causes for these patterns are unknown, though they are not necessarily indicative of non-homogeneities and have not been confirmed statistically.

For most of the sites there seems to be a distinct period of lower than average flows from 1956-1965. This is particularly well illustrated in the tables of one-day excursions, which show many more excursions for the period, than for the remainder of the record (Tables 3.17 and A4.1-A4.8). A ranking of the annual 7-day low flows by year at all of the sites indicates that 50-90 percent of the 10 driest years at each site occurred from 1956-1965. This could well be indicative of a dry low flow period throughout the state of Colorado during that decade.

Tests for the homogeneity of flow records at Littleton and Englewood showed no significant difference in variances or means of low flows at either site before and after the construction of Chatfield Dam. Causative agents for step changes in the low flow regimes at the other sites in this study were lacking. As a result, the data were assumed to be homogeneous at each of the sites and a 30 year period of record was utilized where available. More work could be done to improve detection of non-homogeneities and methods to deal with non-homogeneous records.

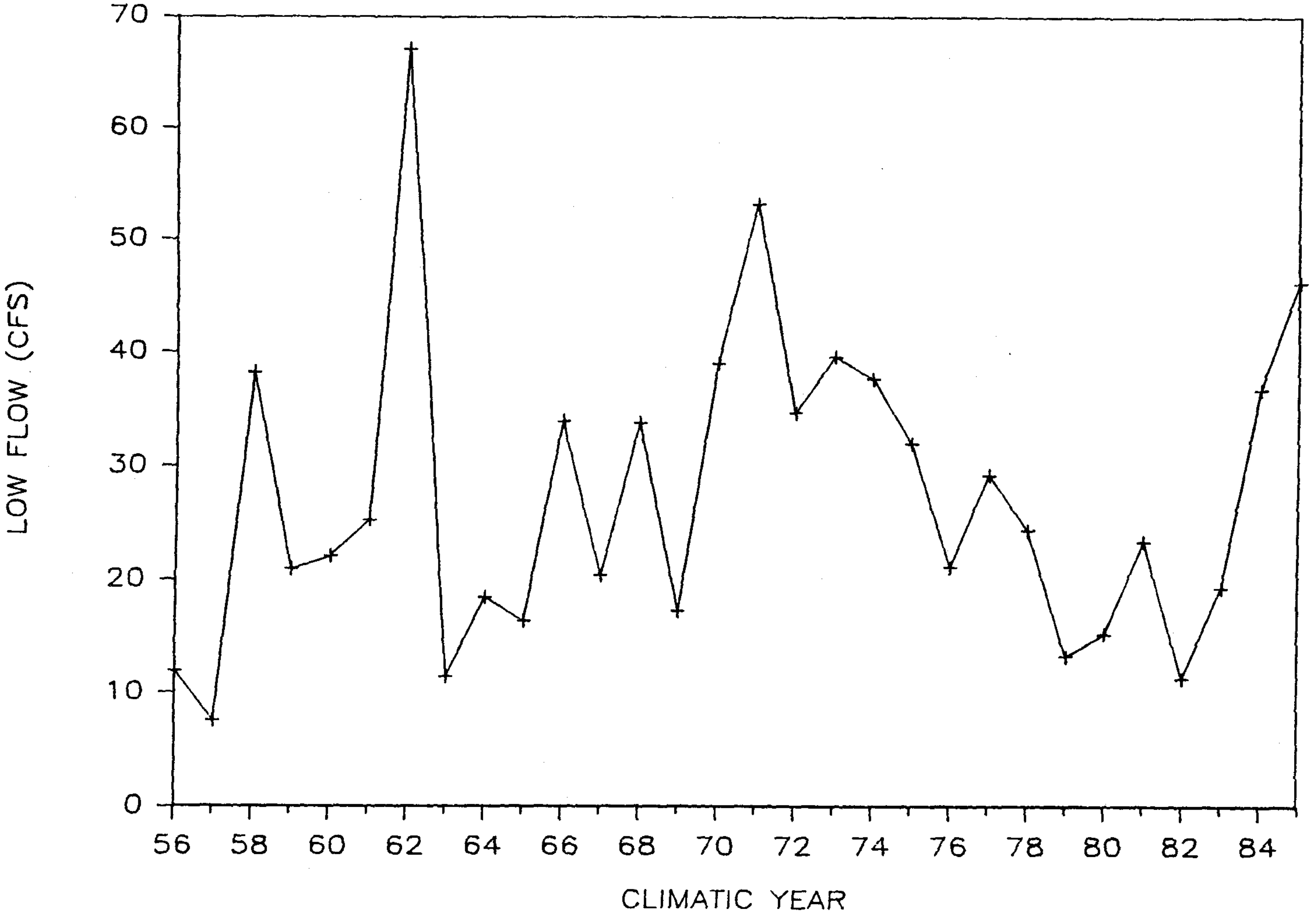


Figure 3.6 Annual 7-day low flows versus time at Littleton.

The results of the low-flow analysis show that the classic 7Q10 was hardly ever experienced during the wet years of the record indicating that this particular statistic may be too stringent at times, while during the dry period it was experienced quite a number of times indicating that this statistics may be too high.

The treatment of cycles and trends is an important issue in the generation of low flow statistics. For analysis of data that exhibits a trend, it is reasonable to select a subset of the total data set from the most current data for analysis. This subset should be sufficiently large to provide a reasonable basis for low-flow statistical analysis (i.e. at least 10 years long). For data that appears to be cyclic, it is more reasonable to use a longer data set (i.e. 30 years) with the assumption that the longer period of record is homogeneous and more accurately reflects the flow regime of the site.

At some sites, it is difficult to determine whether an apparent change in the flow regime is indicative of a trend or cycle. This makes the choice of an appropriate period of record for analysis difficult. As mentioned, a number of the sites in this study seem to exhibit a "dry" period for the first ten years of analysis (1956-1965).

On the one hand, it would be easy to eliminate the earlier data, since it appears to be dissimilar to the more recent data (non-homogeneous), and determine the low flow statistics with the more recent "wet" years. On the other hand, for the "dry" period since the low flow period could occur again, calculating the low flow statistics using the dry year data will provide a margin of safety for the enviroment.

Distribution of Annual and Monthly Low Flows

Results of distribution testing on annual 1 day, 4 day, 7 day and 30 day flows, monthly 7-day low flows and seasonal 7 day flows are shown in Table 3.4A. The results indicate that the log-Pearson type III distribution reasonably fit the various flow statistics at all the sites. If the number in the table is less than the Chi-square statistic of 6.0 then it would be a reasonable assertion that the flow data are log-Pearson type III distributed.

The results of distribution testing for annual 7-day low flows are given in Table 3.4B. these results indicate that, with the exception of Henderson, annual 7-day low flows were normally distributed at all sites using the Chi-square and Shapiro-Wilk test. Henderson flows failed the Shapiro-Wilk test at 5 percent level of significance when no data transformations were utilized. Annual 7-day low flows at Henderson appeared to have had a lognormal distribution.

RESULTS OF FREQUENCY STATISTIC FLOW ANALYSIS

Low flow analysis was made for flows of various durations to correspond to instream aquatic life criteria based on acute and chronic concentrations. Design flows were calculated with two different methods - distribution-based frequency statistics, and the EPA biologically-based empirical method. Annual, seasonal, and monthly design flows were calculated and compared. Low flow events were analyzed for 1-day excursions (moving average flows below a given level), and for run lengths. The results of each type of analysis follow, with specific illustrations given throughout the chapter for various sites (primarily Englewood). Complete low-flow analysis results

Table 3.4A. Chi-square statistics for goodness of fit to the log-Pearson type III distribution.

	Annual Flows				Monthly 7-day flows				Seasonal 7-day flows		
Site	1-day	4-day	7-day	30-day	Mar	Jun	Sep	Dec	Low	Tran	High
Littleton			1.0								
Englewood	3.7	2.3	7.3	5.8	2.7	0.8	1.1	2.4	2.3	1.8	2.7
Henderson			1.0								
Boulder			4.0		4.6	2.8	2.2	1.3	4.0		5.8
Lyons			1.3								
Longmont (daily reg.)			3.7		1.4	5.3	5.9	2.1			
Longmont			1.7		0.4	3.0	2.9	3.4			
Platteville			1.7		1.7	3.7	4.3	6.9			
Fort Collins	6.0	3.0	7.0	5.0	6.0	2.0	0.0	0.0	3.8		1.5

*Reference Chi-square statistic = 6.0

Table 3.4B. Relative scores of normality testing using the Chi-square Goodness-of-Fit and the Shapiro-Wilk Test on annual 7-day low flows for the period of record at each site.

Site	No transformation		Logarithmic		Wilson-Hilferty		Log-Wilson-Hilferty	
	A*	B**	A	B	A	B	A	B
Littleton								
Passed	1	1	1	1	1	1	1	1
Failed	0	0	0	0	0	0	0	0
Englewood								
Passed	1	1	1	1	1	1	1	1
Failed	0	0	0	0	0	0	0	0
Henderson								
Passed	1	0	1	1	1	1	1	1
Failed	0	1	0	0	0	0	0	0
Boulder								
Passed	1	1	1	1	1	1	1	1
Failed	0	0	0	0	0	0	0	0
Lyons								
Passed	1	1	1	1	1	1	1	1
Failed	0	0	0	0	0	0	0	0
Longmont								
Passed	1	1	1	1	1	1	1	1
Failed	0	0	0	0	0	0	0	0
Platteville								
Passed	1	1	1	1	1	1	1	1
Failed	0	0	0	0	0	0	0	0
Fort Collins								
Passed	1	1	1	1	1	1	1	1
Failed	0	0	0	0	0	0	0	0

* A = Chi-square goodness-of-fit test.
** B = Shapiro-Wilk test for normality.
Passed = 5% significance level.

for each of the sites are given in the form of tables and figures in Appendix A.

Annual Design Flows

The results of the annual low flow frequency analyses are presented in two formats - as a table and as a set of frequency curves for each site (Table 3.5, Figure 3.7 and Tables A1.1-A1.20, Figures A1.11-A1.20). Low-flow frequency statistics are given for durations of 1-, 4-, 7- and 30-days and recurrence intervals of 2, 3, 5, 7, 10 and 15 years. As an example, the 7-day moving average low flow occurring once every 10 years on the average (7Q10) from Table 3.5 for Englewood is 28 cfs. Below the annual frequency statistic table is a table of the annual low flows (Table 3.6). An annual low flow may be defined as the lowest moving average of a given duration for any given year. The values in Table 3.6 were fit to a log-Pearson Type III distribution to produce the frequency statistic flows given in Table 3.5.

Frequency curves, which are plots of flow magnitudes versus recurrence intervals for 1-, 4-, 7- and 30-day durations, are given for each site (Figures 3.7, A1.11-A1.20). As the recurrence interval increases, the slopes of the curves flatten out in every case. This is an indication that the difference in magnitude between a 7Q2 and a 7Q3 low flow is much greater than the difference between a 7Q10 and 7Q15.

The frequency curve may be used with interpolation to approximate frequency statistic flows of different recurrence intervals than those previously calculated. For example, a 30Q4 for Englewood may be approximated as 48 cfs (Figure 3.7). In addition, frequency curves may be used to define comparable annual frequency statistics, by drawing a horizontal line through the graph at a given flow value. For example, a

Table 3.5. Annual low flow frequency statistics at Englewood.

Recurrence Interval (years)	Low flow (cfs) Duration 1-day	4-day	7-day	30-day
2	43	48	52	61
3	35	40	43	53
5	30	33	35	44
7	27	30	32	41
10	24	26	28	36
15	22	25	26	34

Table 3.6. Annual low flows for each year of record at Englewood.

Climatic year (4/1-3/31)	Low flow (cfs) Duration 1-day	4-day	7-day	30-day
1956	27	33	35	38
1957	14	14	15	18
1958	54	68	71	78
1959	38	42	44	51
1960	27	31	33	49
1961	29	34	36	46
1962	92	114	119	133
1963	28	30	32	41
1964	19	22	26	44
1965	29	35	36	41
1966	60	65	67	85
1967	40	43	48	50
1968	48	54	60	87
1969	40	43	46	57
1970	66	69	73	99
1971	85	92	95	112
1972	47	65	66	72
1973	60	63	65	73
1974	44	55	64	104
1975	37	45	53	70
1976	38	40	44	51
1977	45	50	60	75
1978	45	47	50	58
1979	38	40	41	54
1980	43	47	51	64
1981	46	46	48	54
1982	38	40	43	54
1983	35	35	37	53
1984	73	75	76	87
1985	79	94	98	136

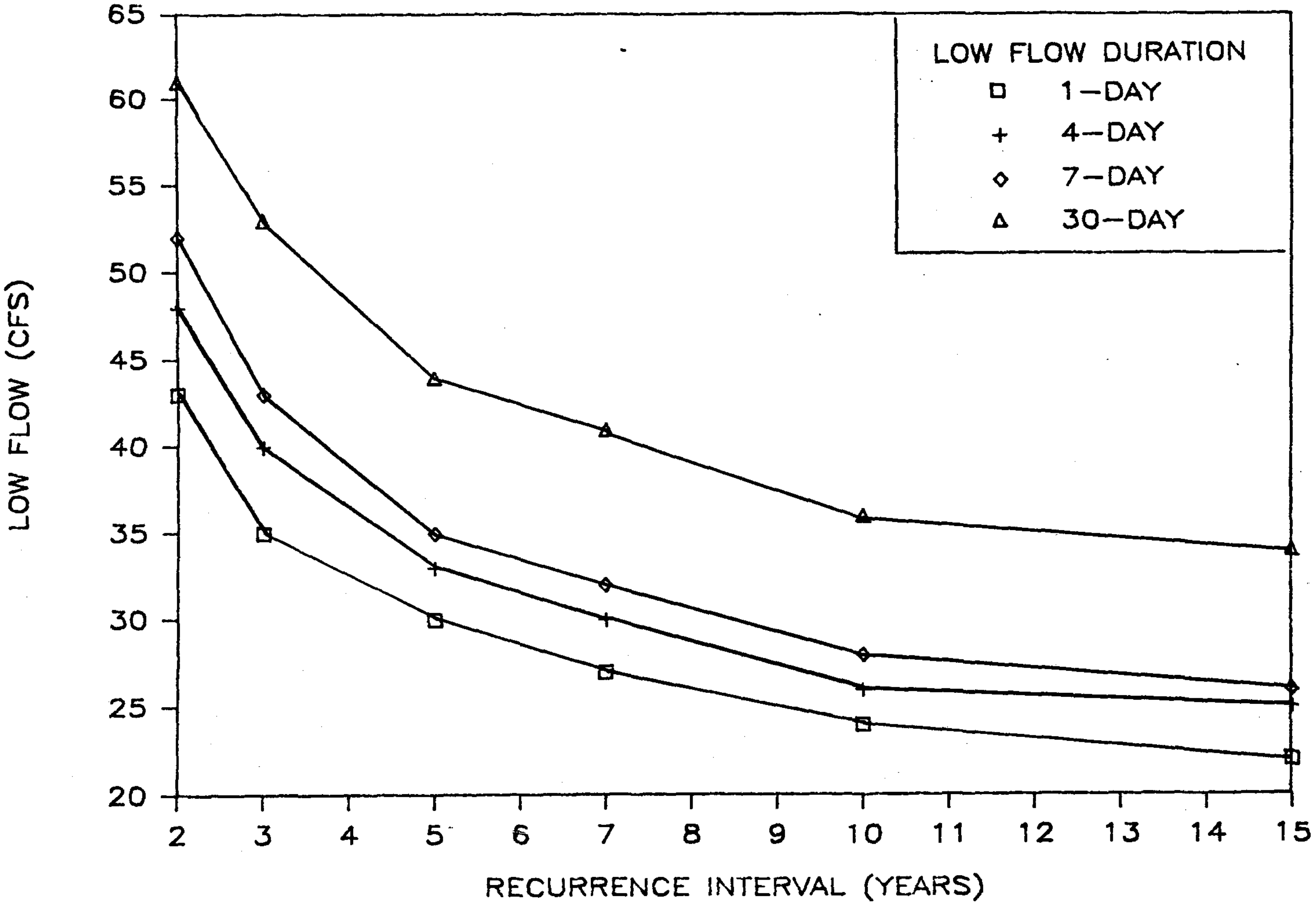


Figure 3.7 Annual frequency curves for 1, 4, 7 and 30-day moving average low flows at Englewood.

line drawn through 40 cfs at Englewood shows that the same flow is approximated by a 1Q2.4, a 4Q3, a 7Q3.8, and a 30Q8.

The annual frequency statistic flows for 1-, 4-, 7- and 30-day durations and 2, 3, 5 and 10 year recurrence intervals were ranked from low to high for each site (Table 3.7). The 1Q10 flow statistic is consistently the lowest, followed by the 4Q10 or 1Q5. The 30Q2 and 30Q3 flow statistics are consistently the highest and second highest flows. In general, the order of the ranked flows varies with the pattern of low flow events. At some sites, duration is a more critical factor in determining flow magnitude and at other sites the recurrence interval is the critical factor.

A second comparison of annual frequency statistic low flows is given in Table 3.8. Percent increases in flow magnitudes varied from site to site. For acute 1Q10 and 1Q3 flows the average increase over all the sites was 81 percent and ranged from 36 percent to 175 percent. The increase in magnitude from chronic 7Q10 to 30Q10 flows average 59 percent and ranged from 0 percent to 177 percent. Increases from chronic 7Q10 to 30Q3 flows averaged 160 percent and ranged from 89 percent to 362 percent.

The period of record chosen for low-flow analysis had a significant effect on the annual frequency statistic flows. This was well-evidenced at Englewood and Longmont. At these sites, analysis was conducted for two different periods of record - a 30-year period from 1956-1985 and a 10-year period from 1976-1985. The results of the analysis are compared in Table 3.9.

The flows calculated with the shorter, more recent period of record are consistently higher than the flows calculated with the longer record. This difference averages about 30 percent and generally increases with increasing recurrence interval. The cause for this significant difference in flow

Table 3.7. Ranking of annual low flow frequency statistics.

Rank	Littleton		Englewood		Henderson		Boulder		Lyons		Longmont*		Longmont**		Platteville		Fort Collins	
(1=low)	cfs	stat	cfs	stat	cfs	stat	cfs	stat	cfs	stat	cfs	stat	cfs	stat	cfs	stat	cfs	stat
1	10	1Q10	24	1Q10	17	1Q10	5.1	1Q10	0.8	1Q10	10	1Q10	12	1Q10	27	1Q10	0.9	1Q10
2	12	1Q5	26	4Q10	22	4Q10	6.9	4Q10	1.2	4Q10	12	4Q10	13	4Q10	29	4Q10	1.2	1Q5
3	12	4Q10	28	7Q10	26	7Q10	7.2	1Q5	1.3	7Q10	12	7Q10	14	7Q10	31	7Q10	1.3	4Q10
4	12	7Q10	30	1Q5	27	1Q5	8.4	7Q10	1.4	1Q5	12	1Q5	14	1Q5	35	1Q5	1.4	7Q10
5	13	4Q5	33	4Q5	36	4Q5	9.0	4Q5	2.1	4Q5	15	1Q3	17	1Q3	38	4Q5	1.4	30Q10
6	14	1Q3	35	1Q3	40	1Q3	9.6	1Q3	2.2	1Q3	15	4Q5	17	4Q5	40	7Q5	1.5	1Q3
7	15	7Q5	35	7Q5	41	7Q5	10.4	7Q5	2.4	7Q5	16	7Q5	18	7Q5	42	1Q3	1.5	4Q5
8	16	30Q10	36	30Q10	46	30Q10	11.5	4Q3	3.3	4Q3	18	30Q10	19	30Q10	43	30Q10	1.6	7Q3
9	17	1Q2	40	4Q3	51	4Q3	11.7	1Q2	3.6	1Q2	19	1Q2	20	4Q3	47	4Q3	1.8	4Q3
10	18	4Q3	43	1Q2	60	1Q2	12.7	7Q3	3.6	30Q10	19	4Q3	21	7Q3	50	7Q3	1.9	1Q2
11	19	7Q3	43	7Q3	61	7Q3	14.3	30Q10	3.8	7Q3	20	7Q3	21	1Q2	53	1Q2	2.0	7Q3
12	22	4Q2	44	30Q5	67	30Q5	14.7	4Q2	4.7	30Q5	22	30Q5	22	30Q5	55	30Q5	2.0	30Q5
13	22	30Q5	48	4Q2	76	4Q2	16.1	7Q2	5.2	4Q2	23	4Q2	24	4Q2	59	4Q2	2.2	4Q2
14	25	7Q2	52	7Q2	89	7Q2	17.1	30Q5	5.9	7Q2	25	7Q2	26	30Q3	64	7Q2	2.4	7Q2
15	27	30Q3	53	30Q3	89	30Q3	20.1	30Q3	6.0	30Q3	26	30Q3	26	7Q2	67	30Q3	2.9	30Q3
16	34	30Q2	61	30Q2	126	30Q2	24.1	30Q2	7.8	30Q2	30	30Q2	31	30Q2	83	30Q2	4.8	30Q2

* values based on regression of daily flows.

** values based on regression of log-transformed daily flows.

Table 3.8. Comparison of annual frequency statistic low flows.

Site	Percent increase in flow magnitude* 1Q10 to 1Q3	7Q10 to 7Q3	30Q10 to 30Q3	7Q10 to 30Q10	7Q3 to 30Q3	7Q10 to 30Q3
Littleton	50	58	59	42	42	125
Englewood	46	54	47	28	23	89
Henderson	135	135	93	77	46	242
Boulder	88	51	40	70	58	139
Lyons	175	192	67	177	58	362
Longmont	50	67	44	50	30	117
Platteville	36	61	56	26	34	116
Fort Collins	67	43	107	0	45	107

* Percent increase = (larger flow - smaller flow) / smaller flow

Table 3.9. Comparison of annual low flow frequency statistics using two different periods of record at Englewood and Longmont.

a. Englewood

Recurrence Interval (years)	1-day		4-day		7-day		30-day	
	A*	B*	A	B	A	B	A	B
2	43	44	48	46	52	49	61	60
3	35	40	40	41	43	45	53	54
5	30	36	33	38	35	41	44	51
10	24	34	26	36	28	38	36	49

b. Longmont (based on a regression of daily flows)

Recurrence Interval (years)	1-day		4-day		7-day		30-day	
	A*	B*	A	B	A	B	A	B
2	21	26	24	28	26	30	31	34
3	17	22	20	26	21	27	26	30
5	14	20	17	23	18	24	22	27
10	12	18	13	21	14	22	19	23

*A period of record 1956-1985
*B period of record 1976-1985

records can be related to either natural dry and wet cycles (dry years occurring in the first 10 years of record), or to a trend in the flow data. Careful analysis of these factors should be incorporated into the choice of a length of record for low-flow analysis, as was discussed in the section on homogeneity of the flow record.

Monthly Design Flows

Monthly frequency statistic low flows are summarized in Table 3.10 for Englewood. The table includes design flows for each month of the year for 1-, 4-, and 7-day durations at 2, 3, 5 and 10 year recurrence intervals. As an example, the monthly 7Q5 for August at Englewood is equal to 79 cfs. On the average, percent increases from one monthly design flow to another (i.e. from 1Q10 to 1Q3) are comparable to percent increases for annual flows given in Table 3.8. However, percent increases are greater for high flow months (e.g. June) than for annual flows and less for low flow months (e.g. January).

Monthly 7-day low flows for each water year of record at Englewood are presented in Table 3.11. The values in this table are the low flows that were fit to a log-Pearson Type III distribution to define the frequency statistics given in Table 3.10. Examination of Table 3.11 and similar tables in the appendix for other sites shows how flows may vary from one month to another on a fairly consistent basis. For example, at Englewood, the average of monthly 7-day low flows for January is 72 cfs and for June is 398 cfs. Although flows vary from month to month there may be even more significant differences from year to year. The month of June at Englewood is a good example, with 7-day low flows ranging from 34 to 2259 cfs.

Figure 3.8 provides a graphical illustration of the differences in frequency statistic flows from one month to another at Englewood. The

Table 3.10. Monthly low flow frequency statistics at Englewood.

Month	7-day low flow (cfs) Recurrence Interval (years)				4-day low flow (cfs) Recurrence Interval (years)				1-day low flow (cfs) Recurrence Interval (years)			
	2	3	5	10	2	3	5	10	2	3	5	10
Jan	67	56	48	41	65	55	47	40	62	53	46	39
Feb	69	58	50	42	66	56	48	41	63	53	46	40
Mar	74	61	52	44	71	58	50	42	67	55	47	40
Apr	107	78	58	43	101	74	56	41	93	67	50	37
May	246	159	110	77	230	148	102	70	204	130	89	60
Jun	234	144	94	60	212	130	85	52	188	113	73	45
Jul	186	137	95	63	162	120	84	55	133	98	69	47
Aug	159	112	79	54	150	101	71	47	130	89	63	43
Sep	76	56	43	32	69	52	40	30	64	48	37	28
Oct	67	50	40	32	63	48	38	31	62	47	37	28
Nov	73	62	52	46	70	60	51	45	66	55	48	43
Dec	70	62	52	46	69	59	51	45	66	56	49	43

Table 3.11. Monthly 7-day low flows for each year of record at Englewood.

Water year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1955	24	45	38	37	38	34	34	110	62	40	261	130
1956	38	59	50	37	37	43	42	215	153	65	39	15
1957	18	41	37	33	37	41	62	270	1190	753	535	73
1958	86	158	95	74	78	71	217	585	307	123	53	44
1959	58	53	51	46	60	61	121	263	232	131	82	33
1960	82	75	65	61	71	94	483	485	245	222	43	36
1961	50	75	83	77	74	102	132	324	130	196	432	274
1962	278	338	150	119	180	155	286	229	282	195	72	35
1963	32	44	60	52	55	50	35	39	34	26	34	107
1964	46	61	68	50	50	58	105	196	118	145	72	40
1965	36	60	51	43	44	60	87	284	402	520	670	335
1966	190	117	80	76	85	66	99	109	85	72	84	49
1967	56	81	68	75	53	47	50	86	135	125	206	96
1968	72	96	86	81	83	83	97	198	154	165	213	108
1969	105	79	70	46	50	68	73	158	722	488	341	103
1970	137	308	219	169	119	126	314	2129	1461	597	220	143
1971	142	129	109	95	120	113	114	427	368	309	230	78
1972	66	75	78	84	82	70	68	117	239	153	139	65
1973	65	78	75	79	93	111	164	1143	981	461	268	64
1974	120	117	97	109	123	222	322	280	153	165	80	53
1975	88	75	75	76	78	79	82	186	352	531	236	119
1976	44	48	64	78	74	74	78	121	100	247	220	113
1977	89	87	88	78	60	64	102	153	60	72	122	58
1978	50	55	58	58	60	56	47	78	53	121	104	48
1979	55	49	41	46	61	63	151	253	493	226	105	51
1980	54	67	84	85	112	100	175	2155	1203	407	166	53
1981	48	71	64	54	62	64	59	115	48	69	74	89
1982	77	54	57	56	46	43	37	79	94	138	305	248
1983	141	59	59	53	48	136	405	1887	2259	845	556	92
1984	76	93	115	107	140	154	292	1393	758	312	664	265
1985	529	281	208	112	98	110	182	1214	572	393	277	64

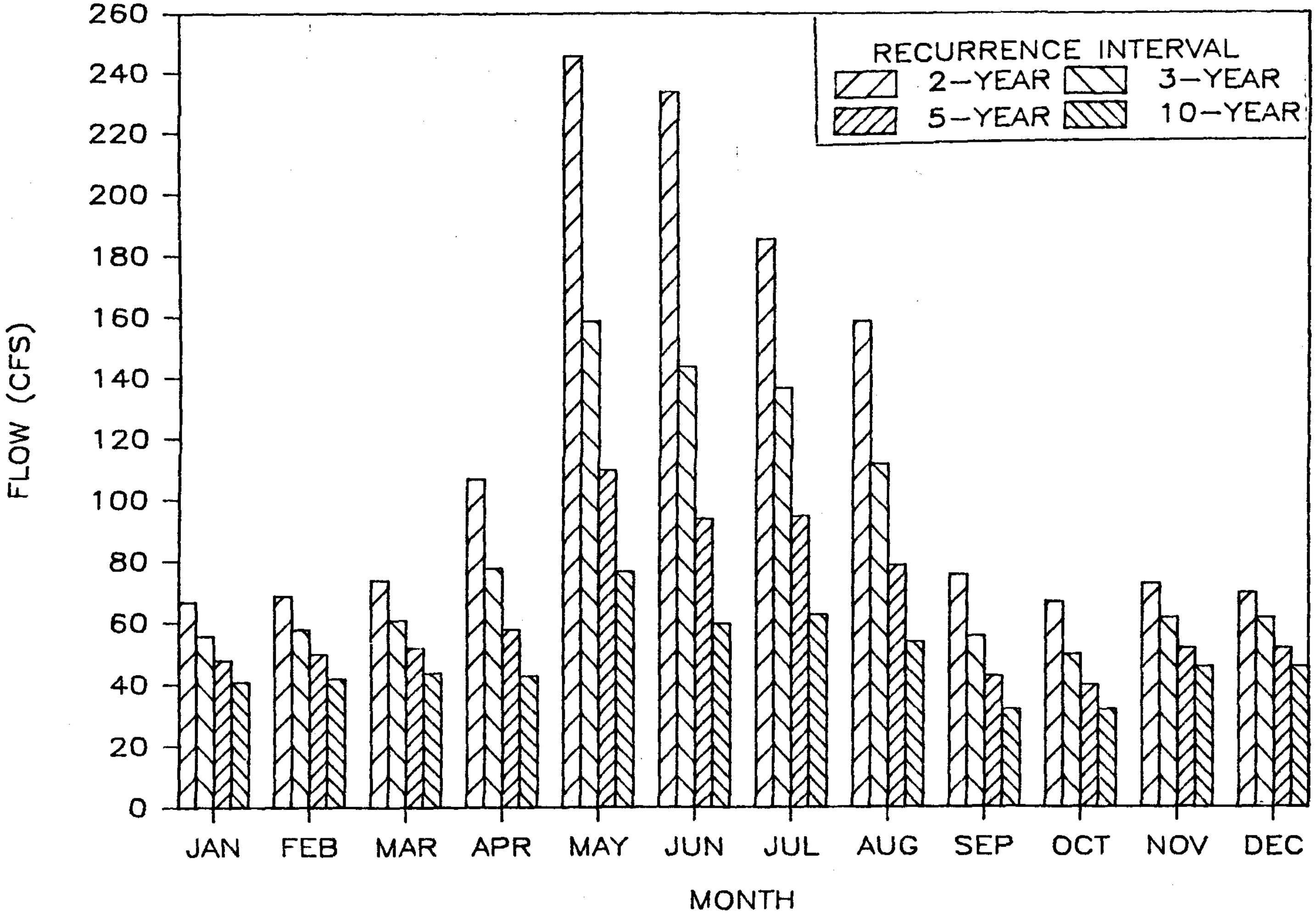


Figure 3.8 Graph of monthly 7-day moving average low flows for 2, 3, 5 and 10 year recurrence intervals at Englewood.

figure includes four bars for each month of the year which give monthly 7-day low flows at 2, 3, 5 and 10 year recurrence intervals.

Monthly low flows for this study were calculated using an overlapping procedure as described in the methodology chapter. This procedure produced values that differ from values calculated without overlapping. The differences in monthly 7-day low flow frequency statistics at Littleton with and without overlapping are illustrated in Table 3.12 (see also Tables A2.10 and A2.11). In general, with the overlapping procedure, monthly low flows for each year had lower means, smaller standard deviations and varying skews when compared to low flows calculated without overlapping. The frequency statistic flows in Table 3.12 are similar, with values occasionally higher with overlapping but more often lower, particularly for high flow months.

In most cases, monthly frequency statistic flows are higher than annual flows. Percent increases of monthly 7Q10 flows over annual 7Q10 flows are given for each month at five sites in Table 3.13. The increases range from 0 percent for several months at Fort Collins to 1914 percent for the month of June at Fort Collins.

Seasonal Design Flows

Months were grouped into seasons to calculate seasonal design flows at four sites - Englewood, Boulder, Longmont and Fort Collins. The year was separated into two to four seasons of low, transition or high flow months, depending on the specific flow characteristics of each site. The statistical criteria used to group the months into seasons at Englewood are summarized in Table 3.14 (see also Tables A3.1-A3.4). The selection of flow seasons using these criteria is a relatively subjective trial and error process. Once an initial selection was made, seasonal flows were calculated

Table 3.12. Comparison of monthly 7-day low flow frequency statistics (with and without overlapping) at Littleton.

Month	7-day low flow (cfs) Recurrence interval (years) 2		3		5		10	
	A*	B*	A	B	A	B	A	B
Jan	32	32	25	25	20	20	15	16
Feb	34	36	27	29	21	23	16	18
Mar	39	43	30	34	24	25	18	19
Apr	65	76	44	51	31	35	21	24
May	162	198	97	114	62	70	39	42
Jun	154	168	94	102	62	66	40	42
Jul	157	164	107	112	75	79	50	53
Aug	130	145	87	103	61	70	40	47
Sep	52	54	38	40	28	29	20	21
Oct	40	39	28	27	21	20	15	15
Nov	38	38	31	30	24	25	21	21
Dec	34	35	26	27	21	21	17	17

*A calculated with overlapping.
B calculated without overlapping.

Table 3.13. Comparison of monthly to annual 7Q10 flows.

Month	% Increase of monthly over annual 7Q10's*			
	Englewood	Boulder	Longmont	Fort Collins
Jan	46	31	42	0
Feb	50	90	58	0
Mar	57	114	42	21
Apr	54	126	42	0
May	175	233	67	29
Jun	114	590	358	1914
Jul	125	662	358	1507
Aug	93	328	275	429
Sep	14	221	175	50
Oct	14	67	67	7
Nov	64	55	75	0
Dec	64	126	75	0

*Percent increase = ((monthly) - (annual)) X 100 / (annual)

Table 3.14. Monthly 7-day low flow statistics used to group months into seasons at Englewood.

Month	Season	Mean	Flow (cfs) Median	SD*	Monthly 7Q3	Seasonal 7Q3
Jan	Low	72	75	29	56	45
Feb	Low	76	71	34	58	45
Mar	Low	84	70	41	61	45
Apr	Transition	146	102	116	78	78
May	High	493	229	619	159	80
Jun	High	434	239	511	144	80
Jul	High	268	195	213	137	80
Aug	High	223	206	181	112	80
Sep	Low	99	73	78	56	45
Oct	Low	95	66	97	50	45
Nov	Low	98	75	75	62	45
Dec	Low	82	70	42	62	45

* Standard deviation

and compared to check the appropriateness of the seasons. Where necessary, months were regrouped into more appropriate seasons.

For the sites analyzed, the grouping of months into seasons varied. Low season months consistently included December, January, February, and March. At some sites, September, October, November, April and/or May were also grouped with the low season. High season months included May, June, July and August. The only month that was consistently high at each of the four sites was June. Transition months included March, April, May, August, September, October and November. The definition of low-flow seasons is a site-specific process and should be based on characteristics at a given site. In this study, the grouping of months was based on flow alone. Other factors that should be considered in the definition of seasons for discharge permitting include variation from month to month in effluent quantity and quality and instream water quality.

Seasonal 7-day low-flow frequency statistics at 2, 3, 5 and 10 year recurrence intervals at Englewood are given in Table 3.15 with seasonal low flows for each year given below in Table 3.16 (see also Tables A3.5-A3.12). The critical importance of how months are grouped is illustrated in Tables 3.15 and 3.16. Seasonal flows for two different sets of seasons were calculated with the first set including low (September-March) and high (April-August) seasons and the second set adding a transition season (April). When April is grouped in the high flow season, the high season flows are much lower than when April is not included in that season (e.g. 7Q2 of 78 cfs compared to 111 cfs). The reason for this significant difference is illustrated in Table 3.16. The lowest flows for the high flow seasons (April-August) may occur in either April or May-August, depending on the year. When April is grouped with May-August, the lowest flow in either

Table 3.15. Seasonal 7-day low flow frequency statistics at Englewood.

Recurrence Interval (years)	Low flow (cfs)			
	Low (Sep-Mar)	Transition (Apr)	High (May-Aug)	High* (Apr-Aug)
2	54	107	111	78
3	45	78	80	60
5	37	58	60	49
10	30	43	44	40

*Based on two seasons only, low and high.

Table 3.16. Seasonal 7-day low flows for each year of record at Englewood.

Year (ending)	Low flow (cfs)			
	Low (Sep-Mar)	Transition (Apr)	High (May-Aug)	High* (Apr-Aug)
1956	37	42	39	39
1957	15	62	270	62
1958	71	217	53	53
1959	44	121	82	82
1960	33	483	43	43
1961	36	132	130	130
1962	119	286	72	72
1963	32	35	26	26
1964	46	105	72	72
1965	36	87	284	87
1966	66	99	72	72
1967	47	50	86	50
1968	72	97	154	97
1969	46	73	158	73
1970	103	314	220	220
1971	95	114	230	114
1972	66	68	117	68
1973	65	164	268	164
1974	64	321	80	80
1975	53	82	186	82
1976	44	78	100	78
1977	60	102	60	60
1978	50	47	53	47
1979	41	151	105	105
1980	51	175	166	166
1981	48	59	48	48
1982	43	37	79	37
1983	48	405	556	405
1984	76	292	312	292
1985	98	182	277	182

*Based on two seasons only, low and high.

season is chosen. Comparison of the last three columns of Table 3.16 illustrates this point.

A comparison of monthly, seasonal, and annual frequency statistic low flows shows that annual flows are consistently less than or equal to seasonal flows which are consistently less than or equal to monthly flows (Figure 3.9). This pattern is due to the variation of flows from one month to another and to the occurrence of minimum flows in different months, for various years. The reasoning for this is similar to that given above for seasonal flows. The lowest values occurring in a year-long period are used to calculate annual statistics and will almost always be lower than any single monthly low-flow statistic which is based on the lowest flows occurring within a much shorter period.

ANALYSIS OF LOW-FLOW EVENTS

Excursion Analysis

The analysis of low-flow events based on 1-day flows below a given annual or monthly flow (1-day excursions) was used to help define the patterns and durations of such events for various low-flow statistics. Four- and thirty-day excursions were also calculated for comparison at one site. The analysis of one-day excursions may be used to help select an appropriate acute design flow (1-day duration). The one-day excursions are not as useful for selecting a chronic design flow, which is of a longer duration (e.g. 4-, 7-, or 30-days). Four- or thirty-day excursions may be used to help select an appropriate chronic design flow, but run lengths, which are discussed in the next section, provide more information and are thus more useful for that purpose.

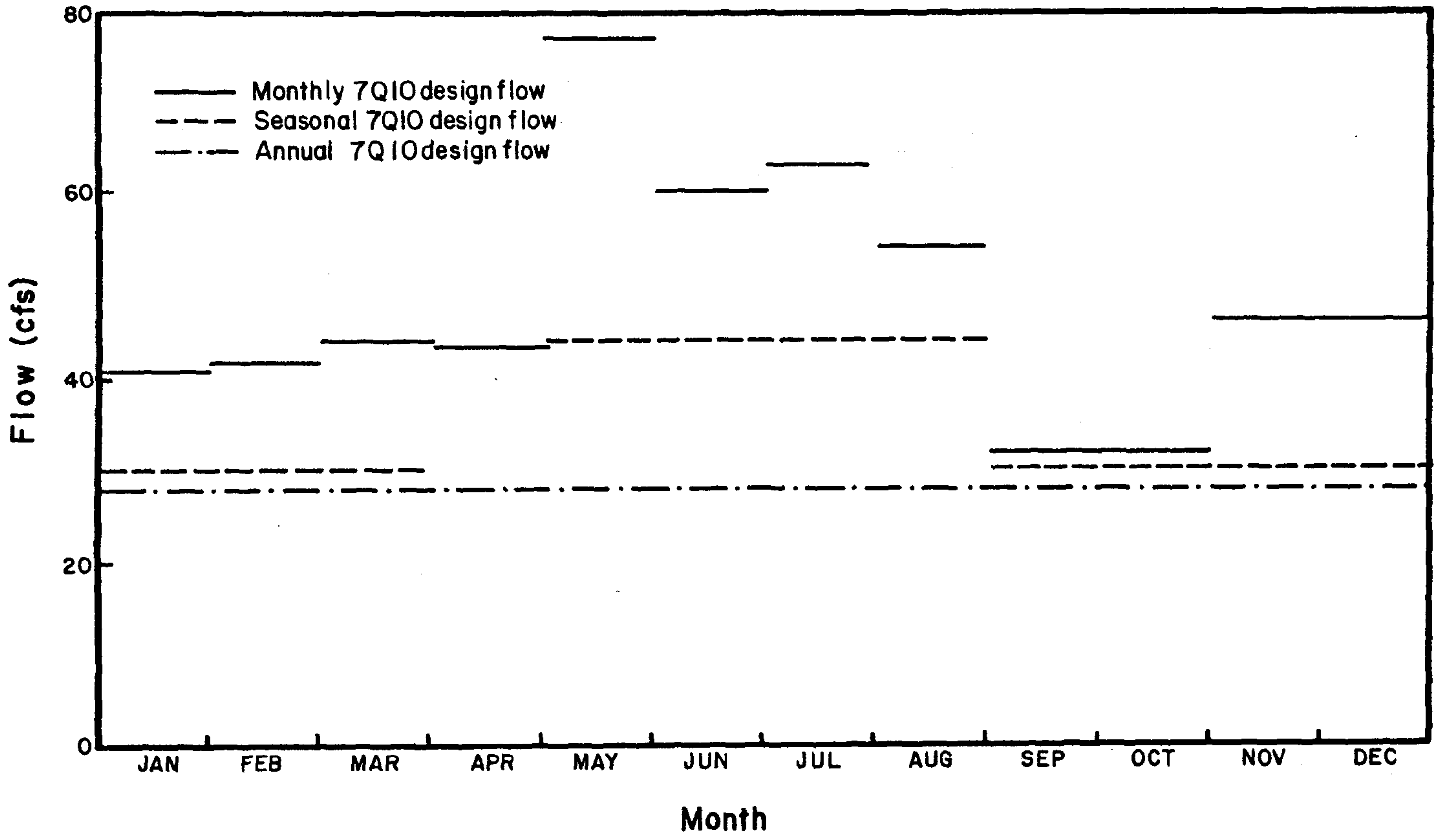


Figure 3.9 Comparison of monthly, seasonal, and annual 7Q10 flows for Englewood.

The results of the 1-day low-flow excursion analysis are summarized for all the sites in Tables A4.1-A4.10. The analysis of 4-day and 30-day excursions at Englewood (Table 3.17) is summarized in Tables A4.9 and A4.10. The number of excursions for each year of record is given for six different annual flows, two acute and four chronic. Total numbers of years and days with excursions are listed at the bottom of the table. With reference to Table 3.17, it can be seen that the flow of the South Platte at Englewood did not go lower than any of the various design annual flows in the years 1984 and 1985. However, in 1964, the 1Q10 of 24 cfs was not exceeded seven times. While the 30Q3 of 53 cfs was not exceeded 100 times; in other words, almost one day in three the river flow was less than the 30Q3.

Summaries for one-day excursions for all the sites are given in Tables 3.18 and 3.19 as percent of total years and total days with excursions, respectively. The number of years with excursions ranges from 3 to 82 percent. The average number of years with excursions over all the sites are: acute flows - 1Q10 average 11 percent, 1Q3 average 31 percent; chronic flows - 7Q10 average 20 percent, 30Q10 average 47 percent, 7Q3 average 49 percent, and 30Q3 average 74 percent. The number of days with excursions varies from 0.1 to 13.4 percent with the following averages: acute flows-1Q10 average 0.25 percent, 1Q3 average 1.1 percent; chronic flows - 7Q10 average 0.5 percent, 30Q10 average 1.9 percent, 7Q3 average 3.2 percent, and 30Q3 average 9.0 percent.

An analysis of excursions below monthly frequency statistic flows for each month of the year showed many more excursions below monthly flows than below annual flows (Tables 3.20 and 3.21). The increase in the number of excursions ranged from 500 percent to 850 percent. This increase is the result of a narrowed range between annual mean flows and monthly design

Table 3.17. One-day low-flow excursions at Englewood.

	Number of excursions for a given annual flow*					
Climatic	Acute flows			Chronic flows		
Year	1Q10	1Q3	7Q10	30Q10	7Q3	30Q3
(4/1-3/31)	(24 cfs)	(35 cfs)	(28 cfs)	(36 cfs)	(43 cfs)	(53 cfs)
1956	0	12	2	16	74	145
1957	41	63	47	69	169	232
1958	0	0	0	0	0	0
1959	0	0	0	0	4	40
1960	0	9	1	9	15	22
1961	0	5	0	6	19	33
1962	0	0	0	0	0	0
1963	0	18	0	18	36	79
1964	7	26	17	28	41	100
1965	0	4	0	8	46	96
1966	0	0	0	0	0	0
1967	0	0	0	0	3	38
1968	0	0	0	0	0	2
1969	0	0	0	0	2	11
1970	0	0	0	0	0	0
1971	0	0	0	0	0	0
1972	0	0	0	0	0	1
1973	0	0	0	0	0	0
1974	0	0	0	0	0	2
1975	0	0	0	0	4	9
1976	0	0	0	0	5	29
1977	0	0	0	0	0	3
1978	0	0	0	0	0	11
1979	0	0	0	0	9	76
1980	0	0	0	0	0	11
1981	0	0	0	0	0	24
1982	0	0	0	0	8	48
1983	0	1	0	4	6	24
1984	0	0	0	0	0	0
1985	0	0	0	0	0	0
Years with excursions (30 total)	2	8	4	8	15	22
Days with excursions (10958 total)	48	138	67	158	441	1036

*Excursion = single 1-day flow below a given level.

Table 3.18. Percent of years with one-day low flow excursions for the period of record.

Site	Percent of years with one-day excursions* Acute flows 1Q10	1Q3	Chronic flows 7Q10	30Q10	7Q3	30Q3
Littleton	3	33	17	73	57	73
Englewood	7	27	13	73	50	73
Henderson	10	30	27	30	50	70
Boulder	18	27	27	54	36	82
Lyons	17	27	20	43	43	70
Longmont	13	27	20	47	50	77
Platteville	10	30	13	33	47	67
Fort Collins	11	44	22	22	56	78

*Excursion = single 1-day flow below a given level.

Table 3.19. Percent of days with one-day low flow excursions for the period of record.

Site	Percent of days with one-day excursions* Acute flows 1Q10	1Q3	Chronic flows 7Q10	30Q10	7Q3	30Q3
Littleton	0.3	1.7	0.6	2.5	3.5	8.8
Englewood	0.4	1.2	0.6	1.4	4.0	9.4
Henderson	0.3	1.1	0.6	1.6	4.2	12.9
Boulder	0.1	0.6	0.3	2.9	1.6	6.3
Lyons	0.3	0.9	0.7	1.7	1.8	5.0
Longmont	0.2	1.5	0.5	2.9	4.0	8.5
Platteville	0.3	1.7	0.5	1.8	3.4	8.0
Fort Collins	0.1	0.3	0.2	0.2	3.5	13.4

*Excursion = single 1-day flow below a given level.

Table 3.20. One-day low flow excursions below monthly 7Q10 flows.

Month	Englewood (30 Years)	Boulder (11 Years)	Longmont (30 Years)	Platteville (30 Years)	Fort Collins (9 Years)
	Total number of excursions* Site				
Jan	46	11	54	53	0
Feb	31	14	39	35	0
Mar	27	28	54	60	0
Apr	30	13	41	22	0
May	29	4	23	31	0
Jun	30	17	47	20	9
Jul	47	8	26	35	22
Aug	26	2	32	36	14
Sep	41	16	43	66	10
Oct	30	12	50	38	7
Nov	15	10	25	37	0
Dec	47	13	36	48	1

*Excursion = single 1-day flow below a given level.

Table 3.21. Comparison of one-day low flow excursions below monthly and annual 7Q10 flows.

		Total number of excursions*		Percent of days	
Site	Flow record (years)	Monthly 7Q10's	Annual 7Q10	Monthly 7Q10's	Annual 7Q10
Englewood	30	397	67	3.6	0.6
Boulder	11	148	25	3.7	0.3
Longmont	30	470	52	4.3	0.5
Platteville	30	481	58	4.4	0.5
Fort Collins	9	63	6	1.9	0.2

*Excursion = single 1-day flow below a given level.

flows. The implication of this analysis is that a more restrictive monthly flow statistic is required to provide a comparable level of protection to that provided by a given annual statistic. A comparable level of risk for excursions below an annual 7Q10 frequency statistic would be provided by a monthly 7Q115 statistic. A monthly 7Q115 flow may be higher or lower than an annual 7Q10, depending on the month.

The use of a monthly flow statistic for dilution purposes may be quite effective in using the natural assimilative capacity of a river during higher flows. During high flows less treatment would be required at the point of discharge while still maintaining downstream uses. However, in order for the use of a monthly design flow to be acceptable it must allow protection of the aquatic system and stream uses at a level of, at least, the conventional 7Q10 using annual values.

Using the concept of equality of risk, the recurrence interval for an equivalent monthly flow can be determined. The assumptions made are:

1) 10 years of daily flow;

2) Monthly data are independent; and

3) Equality of the risk of one or more excursions in a 10 year period.

The risk for one or more excursions of the 7Q10 is found using the equation given below:

$$R = 1 - (1 - \frac{1}{T_R})^N$$

where: R = risk of one or more excursions in N outcomes

N = number of outcomes, 10 when analyzing annual data and 120 when analyzing monthly data

T_R = recurrence interval of the flow.

For the risk of one or more excursions of the 7Q10:

$$R = 1 - (1 - \frac{1}{10})^{10} = 0.65.$$

This means there is a 65 percent chance in the next ten years that there will be one or more flows equal to or less than the 7Q10. Equating the level of risk to monthly flows and solving for the monthly recurrence interval

$$0.65 = 1 - (1 - \frac{1}{T_R})^{120}$$

$$T_R = 114.81 \text{ years}$$

As a result of this analysis, the 7Q115 flow should be calculated for each month. This would then be used as the design flow available for dilution. It should be noted that estimation of an 115 year recurrence interval flow from only 30 years of data or less will require extrapolation of the data increasing more uncertainty in the results as compared to estimating a 10 year recurrence interval flow which requires interpolation of the data and less uncertainty in the results.

The monthly recurrence interval could also be determined by assuming equal risk with the annual flow that one or less excursions occur in a ten year period. This risk is equal to the probability of no excursion of the 10 year flow in 10 years (0.35) plus the probability of only one excursion in 10 years (0.39). The monthly recurrence interval which will theoretically have the identical risk is approximately 120 years. It would appear that the difference of the recurrence intervals are sufficiently small when considering the problem of uncertainty in the data analysis that the 115 year recurrence interval should suffice.

Run Length

Run lengths of low-flow events, or the number of consecutive days with flows below a given level, were calculated at each of the sites for two acute flows (1Q10 and 1Q3) and four chronic flows (7Q10, 7Q3, 30Q10, and 30Q3). The results for Platteville are given in Table 3.22 and for the other sites in Tables A5.1-A5.8. For comparison purposes, run lengths below the annual 30Q3 flow for all the sites are given in Table 3.23. Median run lengths below the 30Q3 in Table 3.22 range from two to four days, as follows: two days - Boulder and Lyons; three days - Littleton, Englewood, Henderson and Fort Collins; four days - Longmont and Platteville.

The run length analysis may be used to evaluate the appropriateness of various chronic or acute design flows for use in discharge permitting. Given specific criteria for the allowable duration of the design flow and frequency of excursions below the design flow, one can select a flow that will meet these requirements. As an example, assume that the criteria allow a chronic design flow duration of 30 days and a frequency of occurrence for excursions below this flow of once every three years. For a 30-year period, 30/3 or 10 excursions would be allowed. At Platteville, the number of 30-day excursions below the 30Q3 is equal to 14.87 (81/30 + 53/30 + 52/30 + 50/30 + 42/30 + 40/30 + 34/30 + 33/30 + 31/30 + 30/30). This exceeds the 10 excursions allowed based on an allowable frequency of once every three years. The number of 30-day excursions below the 30Q10 at Platteville is zero, and the number of 30-day excursions below the 7Q3 is 1.57 (47/30). This kind of analysis can be applied to other sites with various duration and frequency criteria to define appropriate chronic design flows.

BIOLOGICALLY-BASED DESIGN FLOWS

Design flows were calculated with the U.S. EPA biologically-based

Table 3.22. Run lengths of low-flow events for the period of record at Platteville (1956-1985).

1Q10 (27 cfs)		1Q3 (42 cfs)		7Q10 (32 cfs)		7Q3 (50 cfs)		30Q10 (43 cfs)		30Q3 (67 cfs)	
Run length (days)	*Number* of runs	*Run* length (days)	*Number* of runs	*Run* length (days)	*Number* of runs	*Run* length (days)	*Number* of runs	*Run* length (days)	*Number* of runs	*Run* length (days)	*Number* of runs
1	2	1	5	1	2	1	9	1	7	1	23
2	2	2	7	3	1	2	10	2	4	2	14
5	1	3	3	4	1	3	4	3	4	3	7
17	1	4	8	5	2	4	4	4	6	4	6
9	1	5	3	7	1	5	4	5	3	5	5
		6	1	13	1	6	1	6	2	6	4
		7	1	19	1	7	3	7	1	7	4
		8	1			8	1	8	2	8	1
		9	1			9	2	9	2	9	3
		13	1			10	2	13	1	10	2
		15	1			11	1	19	1	11	3
		25	1			12	2	25	1	12	3
		26	1			13	2	26	1	13	2
						17	1			15	1
						18	1			16	1
						20	1			17	1
						27	1			23	1
						29	1			26	1
						47	1			30	1
										31	1
										33	1
										34	1
										40	1
										42	1
										50	1
										52	1
										53	1
										81	1

Table 3.23. Run lengths of low flow events for flows below the annual 30Q3 for the period of record.

Littleton (1956-1985)		Englewood (1956-1985)		Henderson (1956-1985)		Boulder (1961-1970)		Lyons (1956-1985)		Longmont (1956-1985)		Platteville (1956-1985)		Fort Collins (1977-1985)	
Run length (days)	Number of runs	Run length (days)	Number of runs	Run length (days)	Number of runs	Run length (days)	Number of runs	Run length (days)	Number of runs	Run length (days)	Number of runs	Run length (days)	Number of runs	Run length (days)	Number of runs
1	43	1	41	1	26	1	16	1	51	1	30	1	23	1	17
2	21	2	18	2	18	2	7	2	23	2	11	2	14	2	8
3	17	3	15	3	12	3	3	3	14	3	7	3	7	3	3
4	8	4	7	4	7	4	2	4	8	4	11	4	6	4	4
5	6	5	12	5	5	5	3	5	2	5	5	5	5	5	2
6	7	6	8	6	3	6	2	6	4	6	5	6	4	6	2
7	6	7	5	7	2	8	1	7	2	7	3	7	4	7	2
8	5	8	2	8	4	9	1	8	1	8	3	8	1	8	2
9	3	9	4	9	4	10	1	9	2	9	3	9	3	10	2
10	3	10	1	10	2	11	3	10	3	10	3	10	2	12	3
1	1	11	4	11	5	13	1	11	2	11	1	11	3	13	1
13	2	12	3	12	1	17	1	12	1	12	5	12	3	17	1
14	1	13	6	13	2	43	1	15	1	13	1	13	2	23	1
15	1	14	3	14	2			16	2	16	1	15	1	24	1
16	3	15	2	15	3			18	1	18	2	16	1	40	1
17	3	16	1	16	4			21	2	21	1	17	1	70	1
18	1	17	1	20	1			23	1	22	1	23	1	93	1
19	1	18	1	21	1			24	1	27	1	26	1		
20	1	19	2	25	1			29	1	30	1	30	1		
22	1	22	1	29	1			50	1	32	2	31	1		
28	1	34	1	33	1					38	1	33	1		
35	1	55	1	37	1					43	1	34	1		
46	1	71	1	78	1					45	1	40	1		
50	1	137	1	87	1					111	1	42	1		
51	1			108	1					116	1	50	1		
129	1			138	1							52	1		
				203	1							53	1		
												81	1		

method for acute and chronic conditions. This method is based on partial-series analysis as compared to the annual series analysis used to define frequency statistic low flow.

Biologically-based design flows were calculated for acute (1-day duration) and chronic (4- and 30-day durations) concentrations at all the sites. The values are given in Tables 3.24-3.26 along with comparable frequency statistic flows and percent differences. The flow statistic used to compare to the acute 1-day, 3-year flow was the 1Q10. The chronic 4-day, 3-year and 30-day, 3-year flows were compared to the 7Q10 and 30Q10, respectively. The number of acceptable and actual excursions are also listed for each flow. Excursions are defined differently for each type of calculation (acute and chronic) as described in the methods section.

Acute 1-day 3-year design flows were similar in magnitude to the 1Q10 or 1Q15 frequency statistic flows. Chronic 30-day 3-year flows were approximated by 30Q10 or 30Q15 flows. These findings correspond closely to the results of an EPA study which analyzed 60 streams across the nation, including a number in this region (U.S. EPA, 1966).

In four out of eight cases, or 50 percent, the 1Q10 flow was higher than the 1-day, 3-year flow. This compares to 65 percent of 60 streams tested in a recent EPA study (U.S. EPA, 1986). The 7Q10 flow was higher than the 4-day, 3-year flow at six out of eight sites or 75 percent, as compared to 77 percent in the EPA study. The 30Q10 flow was higher than the 30-day, 3-year flow in five out of eight cases or 62 percent, as compared to 0 percent in the EPA study.

Coefficients of variation based on the complete daily flow record were calculated at each site and are listed in the first column of Table 3.26. The values range from 1.51 to 2.82 and are within the range of values for

Table 3.24. Biologically-based acute design flows and comparison to 1Q10 flows.

Site (acceptable no of excs)	1Q10 flow (cfs)	Number of 1-day excursions	Bio-based 1-day 3-yr flow (cfs)	Number of 1-day excursions	% Difference in flows*
Littleton (10.17)	10	9	10.0	9	0.0
Englewood (10.17)	24	10	26.0	10	7.7
Henderson (10.17)	17	16	12.0	9	-41.7
Boulder (3.49)	5	1	6.0	3	16.7
Lyons (10.17)	0.8	19	0.5	5	-60.0
Longmont (10.17)	10	15	9	10	-11.1
Platteville (10.17)	27	11	26.0	8	-3.8
Fort Collins (3.17)	0.9	3	1.3	3	30.8

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

Table 3.25. Biologically-based chronic design flows and comparison to 7Q10 flows.

Site (acceptable no of excs)	7Q10 flow (cfs)	Number of 4-day excursions	Bio-based 4-day 3-yr flow (cfs)	Number of 4-day excursions	% Difference in flows*
Littleton (10.17)	12	16.25	10.7	8.50	-12.1
Englewood (10.17)	28	10.00	29.9	10.00	6.4
Henderson (10.17)	26	17.25	15.9	10.00	-63.5
Boulder (3.49)	8	5.00	6.9	2.75	-15.9
Lyons (10.17)	1.3	21.00	0.8	9.50	-62.5
Longmont (10.17)	12	20.00	10.8	10.00	-11.1
Platteville (10.17)	31	15.50	27.9	9.50	-11.1
Fort Collins (3.17)	1.4	1.50	1.5	3.00	6.7

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

Table 3.26. Biologically-based chronic design flows based on a 30-day moving average and comparison to 30Q10 flows.

Site (acceptable no of excs)	Coefficient of variation	30Q10 flow (cfs)	Number of 30-day excursions	Bio-based 30-day 3-yr flow (cfs)	Number of 30-day excursions	% Difference in flows*
Littleton (10.17)	1.84	17	11.07	16.5	10.17	-3.1
Englewood (10.17)	1.77	36	4.17	38.3	10.17	6.0
Henderson (10.17)	1.52	46	13.03	43.0	8.67	-7.0
Boulder (3.49)	1.38	14	3.30	14.8	3.47	5.7
Lyons (10.17)	1.61	3.6	15.83	2.5	9.80	-44.0
Longmont 10.17	1.51	18	17.93	15.7	9.63	-86.2
Platteville (10.17)	1.51	43	8.57	44.5	10.17	3.4
Fort Collins (3.17)	2.82	1.4	0.00	1.9	3.17	-27.3

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

the 60 rivers in the EPA study (U.S. EPA, 1986). Coefficients of variation as mentioned previously have been used as criteria for determining whether or not 30-day flows may be used in place of shorter duration flows for chronic flow calculations. A low coefficient of variation is considered indicative of a relatively stable flow regime. In the EPA report, a coefficient of variation of approximately 1.0 or below was used to define sets of flow data appropriate for a 30-day averaging period instead of the four day averaging period.

CHAPTER 4 - DESIGN FLOWS AND EFFLUENT LIMITS

The relationship between given design flows and corresponding discharge permit limits was examined to help evaluate the appropriateness of various flows. Theoretical effluent limits were calculated on the basis of various annual and monthly design flows to assess the potential implications for dischargers. Two water quality variables were included in the analysis - un-ionized ammonia and a conservative element, copper.

AMMONIA

Currently in the State of Colorado, un-ionized ammonia is of great concern to water quality managers and dischargers. The State of Colorado Water Quality Control Commission has recently revised nitrogenous water quality standards, including standards for ammonia. It appears that a number of municipal wastewater treatment facilities throughout the state may have difficulty in meeting new instream un-ionized ammonia limits without the addition of additional treatment facilities. The issue is a multi-million dollar concern.

Behavior and Effects

Ammonia is a naturally occurring substance in most stream ecosystems, although concentrations may be higher due to human activity, specifically discharges from municipal wastewater treatment plants. Sources of ammonia include: organic matter decomposition, surface runoff and groundwater, wastewater treatment plants, and industrial processes (NRC, 1979). In an aqueous ammonia solution, un-ionized ammonia (NH_3) exists in equilibrium with the ammonium ion (NH_4^+) and the hydroxide ion (OH^-). It should be noted that un-ionized ammonia concentrations are frequently expressed as milligrams per liter of ammonia as nitrogen (NH_3 mg/l-N). This means that the weight of nitrogen alone is considered in concentration values. The value of ammonia as nitrogen is equal to (0.822) x (ammonia as ammonia) based on the ratio of atomic weights.

The un-ionized form of ammonia is primarily responsible for its toxic effects on aquatic life (U.S. EPA, 1984a). A number of factors affect the percent of total ammonia that is un-ionized, including pH, temperature, ionic strength, and total dissolved solids (U.S. EPA, 1984a). pH and temperature are considered the most critical factors, with percent un-ionized ammonia increasing as either factor increases. A table of values for percent un-ionized ammonia at temperatures ranging from 0-30°C and at pH's ranging from 6.0-10.0 was developed by Emerson (1975) and is reproduced in Table 4.1. The percent of total ammonia (NH_3 + NH_4^+) that is made up by the un-ionized form ranges from less than 0.01 to approximately 90 percent over the range of possible pH and temperature conditions.

The toxicity of ammonia in solution is dependent not only on the percent un-ionized ammonia, but on a number of other factors as well. Ambient conditions may provide factors that either increase or decrease the overall toxicity of un-ionized ammonia. These factors include: dissolved oxygen concentration, pH, temperature, carbon dioxide content, and salinity.

Table 4.1 **Percent NH_3 in aqueous ammonia solutions for 0-30 C and pH 6-10.**

Temp. (C)	pH 6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0
0	.00827	.0261	.0826	.261	.820	2.55	7.64	20.7	45.3
1	.00899	.0284	.0898	.284	.891	2.77	8.25	22.1	47.3
2	.00977	.0309	.0977	.308	.968	3.00	8.90	23.6	49.4
3	.0106	.0336	.106	.335	1.05	3.25	9.60	25.1	51.5
4	.0115	.0364	.115	.363	1.14	3.52	10.3	26.7	53.5
5	.0125	.0395	.125	.394	1.23	3.80	11.1	28.3	55.6
6	.0136	.0429	.135	.427	1.34	4.11	11.9	30.0	57.6
7	.0147	.0464	.147	.462	1.45	4.44	12.8	31.7	59.5
8	.0159	.0503	.159	.501	1.57	4.79	13.7	33.5	61.4
9	.0172	.0544	.172	.542	1.69	5.16	14.7	35.3	63.3
10	.0186	.0589	.186	.586	1.83	5.56	15.7	37.1	65.1
11	.0201	.0637	.201	.633	1.97	5.99	16.8	38.9	66.8
12	.0218	.0688	.217	.684	2.13	6.44	17.9	40.8	68.5
13	.0235	.0743	.235	.738	2.30	6.92	19.0	42.6	70.2
14	.0254	.0802	.253	.796	2.48	7.43	20.2	44.5	71.7
15	.0274	.0865	.273	.859	2.67	7.97	21.5	46.4	73.3
16	.0295	.0933	.294	.925	2.87	8.54	22.8	48.3	74.7
17	.0318	.101	.317	.996	3.08	9.14	24.1	50.2	76.1
18	.0343	.108	.342	1.07	3.31	9.78	25.5	52.0	77.4
19	.0369	.117	.368	1.15	3.56	10.5	27.0	53.9	78.7
20	.0397	.125	.396	1.24	3.82	11.2	28.4	55.7	79.9
21	.0427	.135	.425	1.33	4.10	11.9	29.9	57.5	81.0
22	.0459	.145	.457	1.43	4.39	12.7	31.5	59.2	82.1
23	.0493	.156	.491	1.54	4.70	13.5	33.0	60.9	83.2
24	.0530	.167	.527	1.65	5.03	14.4	34.6	62.6	84.1
25	.0569	.180	.566	1.77	5.38	15.3	36.3	64.3	85.1
26	.0610	.193	.607	1.89	5.75	16.2	37.9	65.9	85.9
27	.0654	.207	.651	2.03	6.15	17.2	39.6	67.4	86.8
28	.0701	.221	.697	2.17	6.56	18.2	41.2	68.9	87.5
29	.0752	.237	.747	2.32	7.00	19.2	42.9	70.4	88.3
30	.0805	.254	.799	2.48	7.46	20.3	44.6	71.8	89.0

(from "Ambient Water Quality Criteria for Ammonia," U.S. EPA, 1985)

In addition, acclimation of populations to ammonia, changing periods of exposure, and various levels of physical activity may influence toxic effects on fish (Subcommittee on Ammonia, 1979; U.S. EPA, 1984a).

The effects of un-ionized ammonia on aquatic species has been widely researched for a variety of conditions. Many of the results have recently been compiled in the EPA document, "Ambient Aquatic Life Water Quality Criteria for Ammonia" (U.S. EPA, 1984a). Acutely toxic effects have been detected in invertebrate species at levels of 0.53-22.8 mg/l NH_3, and in fish species from 0.083-4.60 mg/l NH_3. Acute effects on fish may include: loss of equilibrium, hyperexcitability, increased breathing, cardiac output, and oxygen uptake and in extreme cases - convulsions, coma and death. Chronic effects in invertebrates have been detected at levels of 0.304-1.2 mg/l NH_3 and in fish at 0.0017-0.612 mg/l NH_3. These effects include: reduction in hatching success, reduction in growth rate and development, and pathological changes.

Water Quality Models

A number of models have been developed for predicting concentrations of water quality variables, including total and un-ionized ammonia. A general description of five different approaches to modelling ammonia are presented, with emphasis on the method used in this study.

The QUAL2E model, developed for the U.S. EPA, is capable of simulating 15 different water quality constituents in a dynamic or steady state. The model is based on a one-dimensional advection-dispersion mass transport equation that is numerically integrated over space and time for each water quality constituent. Analysis by the model includes the effects of advection, dispersion, dilution, constituent reactions and interactions, and sources and sinks (Brown, 1985). Although, total ammonia may be analyzed, the model does not calculate percent un-ionized ammonia.

The USGS has used another model developed by Bauer (1979), called a one-dimension steady-state water-quality model. It is based on the Streeter Phelps oxygen-sag equation with additional considerations for nitrogenous and conservative compounds. The model was used in a recent study of the effects of wastewater effluent on the South Platte (Spahr, 1985). In the South Platte study, un-ionized ammonia concentrations were calculated using a method reported by Skarheim (1973). Values simulated by the model for temperature, pH, total ammonia, and dissolved solids were used with equilibrium dissociation constants for ammonia to predict un-ionized ammonia levels downstream of an effluent discharge. To account for variations in pH, a range of values was used to represent worst and best cases for cold and warm water conditions. The pH cases were defined by using various values for: 1) pH depression caused by the wastewater effluent, and 2) pH recovery downstream (Spahr, 1985).

Another model has been developed by the EPA to calculate present un-ionized ammonia, and allowable discharge concentrations. The model is called WLANH3 and was developed by Willingham (1985). Inputs to the model include information about upstream and effluent water quality (temperature, pH, upstream ammonia alkalinity, and total dissolved solids) and flows. An admixture pH value for the combined upstream and effluent flows is determined on the basis of the alkalinity and total carbonate carbon levels, using a modified graphical procedure (Stumm and Morgan, 1981). Combined values for the other water quality variables are computed using a simple mixing equation for upstream and effluent flows.

Although the model does account for the four major factors affecting the percent un-ionized ammonia, accuracy of the results may be limited due to the models inability to incorporate pH changes downstream. It appears that pH in some streams is highly variable both spatially and over time due to biological activity and buffering capacities (Spahr, 1985; Lewis, 1986). As a result, pH and percent un-ionized ammonia at the end of the mixing zone may be very different from those values predicted by the model.

The recent recommendations of the Colorado State Nitrogen Cycle Committee (Nitrogen Cycle, 1986) provide a new approach to the determination of ammonia effluent limits. The method requires three main steps to go from instream ammonia criteria to permit limits. The first step is to calculate total ammonia allowed instream for various pH-temperature pairs and corresponding percents un-ionized ammonia. The equation to be used is as follows:

$$\text{Total Ammonia Allowed} = NH_3 \text{ mg/l} - N\ (1 + 10^{pK-pH})$$

where $pK = -0.03242T + 10.063$

T = temperature at °C

The second step takes the range of total ammonia values and applies a statistical evaluation to determine a single value for total ammonia allowed. If the set of values for total ammonia values is normally distributed, then the following equation is applied.

$$\text{Single Total Ammonia Value} = \bar{X} - s$$

where $\bar{X}$ = mean of total ammonia values

s = standard deviation of total ammonia values

If the set of ammonia values is skewed to the right (with more low values), then only the values below the 15th percentile should be used in the following equation.

$$\text{Single Total Ammonia Value} = \bar{X}_{15}$$

where $\bar{X}_{15}$ = mean of total ammonia values below the 15th percentile

The single total ammonia value calculated in this manner represents the maximum 1-day (acute) or 4-day (chronic) total ammonia concentration allowed instream at the end of the mixing zone.

The third step in the procedure is the calculation of a permit limit using the following mixing equation.

$$\text{Permit Limit} = \frac{A_T(Q_U + Q_E) - (Q_U * A_U)}{Q_E}$$

where A_T = single total ammonia values downstream from discharge point

Q_U = upstream flow (design flow)

Q_E = effluent flow

A_U = upstream ammonia concentration

Permit limits may be calculated with this method for either acute or chronic levels of protection, depending on the instream criteria and design flows used. One drawback of the method is that it does not account for changes in pH downstream of the discharger.

EPA Un-Ionized Ammonia Program

The EPA Region VIII Office is currently using a simplified computerized approach to determining ammonia effluent limits for various pH and temperature conditions. The method requires the input of upstream un-ionized ammonia levels, instream criteria, upstream flow and effluent flow.

Given these values, the program produces a matrix of effluent ammonia limits for a specified range of pH and temperature values. The calculations made by the program apply to the point of mixing, near the effluent discharge and do not apply to points downstream where variable pH and ammonia decay may need to be considered. The equations used in the EPA program are included in Appendix B. Calculations are made on the basis of a weighted mixture of the effluent flow and streamflow.

The simplified EPA ammonia program was used in this study because it allows a relatively direct focus on the effect of design flows on ammonia effluents. pH and temperature effects may be analyzed separately by examining the matrix for a given design flow, rather than being incorporated directly into a single effluent limit that masks the effect of various flows.

The analysis of effluent ammonia limits was carried out at four study sites, with wastewater treatment facilities nearby. The sites included: Englewood, Boulder, Longmont, and Fort Collins. For the purposes of this study, upstream un-ionized ammonia levels were set equal to zero. A few program runs with more realistic upstream concentrations were run for comparison purposes. Effluent flows from the four municipal wastewater treatment facilities in the analysis were set equal to the rated design capacity flow for each plant. This is the value generally used in writing a discharge permit. In some cases, actual or predicted future effluent flows are used in permitting. For comparison, runs were made at a few of the sites with actual effluent flows.

Effluent analysis was made for both chronic and acute conditions. Three different chronic upstream or design flows (7Q10, 30Q10, 30Q3) were analyzed at each site. For each of these flows, two values for chronic instream ammonia limits were used (0.06 and 0.10 mg/l-N of un-ionized ammonia). These are values currently being considered for future use within the State of Colorado. Acute flows (1Q10, 1Q3) were analyzed with an instream acute criterion of 0.20 mg/l-N. The value for an acute criterion may vary greatly depending on the given conditions, and 0.20 was chosen only as a value within the range of possible values.

Results of Ammonia Effluent Limit Analysis

The results of the analysis of ammonia effluent limits by the EPA program are presented as a set of tables in a matrix format (Table 4.2). Ammonia effluent limits within the matrix correspond to specific pH and temperature pairs (for combined upstream and effluent) for values ranging from 6.5-9.0 pH units and 3.0-25.0 degrees centigrade. Each print-out lists the inputs used: stream, discharger, upstream flow, upstream ammonia concentration, un-ionized ammonia instream criteria (or standard) and effluent or discharge flow. All ammonia values are given as mg/l-N. Effluent ammonia limits that are below 15.0 mg/l-N follow a stair-step pattern that is delineated in Table 4.2. Advanced treatment requirements are likely for pH-temperature conditions to the right of this 15.0 mg/l-N line. Typical effluent and upstream values for pH and temperature at three of the sites are given in Table 4.3 to provide a framework for the analysis.

To allow for a better comparison of various design flows, pH-temperature matrices have been drawn from the original tables to include effluent limits for three different chronic flows or two different acute flows at a single site (Figures 4.1-4.4 and Appendix B figures). Figure 4.1 is shaded to show the pH-temperature conditions which would require advanced treatment given an instream standard of 0.06 mg/l-N. The area within the figure that has no shading at all represents conditions where secondary

Table 4.2 Ammonia effluent limits for the Cities of Littleton and Englewood given in a pH-temperature matrix as calculated by the EPA ammonia program.

DISCHARGER: ENGLEWOOD STREAM: SOUTH PLATTE
UPSTREAM FLOW IN CFS: 28.0
UPSTREAM AMMONIA IN mg/l: 0.0
UN-IONIZED AMMONIA STANDARD IN mg/l X 10 0.6
DISCHARGE FLOW IN MGD: 28.0

												pH														
DEGREES CENTIGRADE	6.5	6.6	6.7	6.8	6.9	7.0	7.1	7.2	7.3	7.4	7.5	7.6	7.7	7.8	7.9	8.0	8.1	8.2	8.3	8.4	8.5	8.6	8.7	8.8	8.9	9.0
3.0	*****	*****	*****	*****	*****	93.5	74.3	59.1	46.9	37.3	29.6	23.6	18.7	14.9	11.9	9.4	7.5	6.0	4.8	3.8	3.1	2.4	2.0	1.6	1.3	1.0
4.0	*****	*****	*****	*****	*****	86.2	68.5	54.4	43.2	34.4	27.3	21.7	17.3	13.7	10.9	8.7	6.9	5.5	4.4	3.5	2.8	2.3	1.8	1.5	1.2	1.0
5.0	*****	*****	*****	*****	*****	79.4	63.1	50.2	39.9	31.7	25.2	20.0	15.9	12.7	10.1	8.0	6.4	5.1	4.1	3.3	2.6	2.1	1.7	1.4	1.1	0.9
6.0	*****	*****	*****	*****	92.2	73.3	58.2	46.3	36.8	29.2	23.2	18.5	14.7	11.7	9.3	7.4	5.9	4.7	3.8	3.0	2.4	1.9	1.6	1.3	1.0	0.8
7.0	*****	*****	*****	*****	85.1	67.6	53.7	42.7	33.9	27.0	21.4	17.1	13.6	10.8	8.6	6.8	5.5	4.4	3.5	2.8	2.2	1.8	1.4	1.2	0.9	0.8
8.0	*****	*****	*****	98.9	78.6	62.4	49.6	39.4	31.3	24.9	19.8	15.8	12.5	10.0	7.9	6.3	5.1	4.0	3.2	2.6	2.1	1.7	1.3	1.1	0.9	0.7
9.0	*****	*****	*****	91.4	72.6	57.7	45.8	36.4	29.0	23.0	18.3	14.6	11.6	9.2	7.3	5.9	4.7	3.7	3.0	2.4	1.9	1.5	1.2	1.0	0.8	0.7
10.0	*****	*****	*****	84.5	67.1	53.3	42.4	33.7	26.8	21.3	16.9	13.5	10.7	8.5	6.8	5.4	4.3	3.5	2.8	2.2	1.8	1.4	1.2	0.9	0.8	0.6
11.0	*****	*****	98.3	78.1	62.1	49.3	39.2	31.2	24.8	19.7	15.7	12.5	9.9	7.9	6.3	5.0	4.0	3.2	2.6	2.1	1.7	1.3	1.1	0.9	0.7	0.6
12.0	*****	*****	91.0	72.3	57.4	45.7	36.3	28.8	22.9	18.2	14.5	11.5	9.2	7.3	5.8	4.7	3.7	3.0	2.4	1.9	1.5	1.2	1.0	0.8	0.7	0.6
13.0	*****	*****	84.2	66.9	53.2	42.3	33.6	26.7	21.2	16.9	13.4	10.7	8.5	6.8	5.4	4.3	3.4	2.8	2.2	1.8	1.4	1.2	0.9	0.8	0.6	0.5
14.0	*****	98.2	78.1	62.0	49.3	39.2	31.1	24.7	19.7	15.7	12.5	9.9	7.9	6.3	5.0	4.0	3.2	2.6	2.1	1.7	1.3	1.1	0.9	0.7	0.6	0.5
15.0	*****	91.1	72.3	57.5	45.7	36.3	28.9	22.9	18.2	14.5	11.5	9.2	7.3	5.8	4.7	3.7	3.0	2.4	1.9	1.5	1.2	1.0	0.8	0.7	0.6	0.5
16.0	*****	84.4	67.1	53.3	42.4	33.7	26.8	21.3	16.9	13.5	10.7	8.5	6.8	5.4	4.3	3.5	2.8	2.2	1.8	1.4	1.2	0.9	0.8	0.6	0.5	0.4
17.0	98.6	78.4	62.3	49.5	39.3	31.3	24.8	19.8	15.7	12.5	10.0	7.9	6.3	5.0	4.0	3.2	2.6	2.1	1.7	1.3	1.1	0.9	0.7	0.6	0.5	0.4
18.0	91.6	72.7	57.8	45.9	36.5	29.0	23.1	18.3	14.6	11.6	9.2	7.4	5.9	4.7	3.7	3.0	2.4	1.9	1.5	1.3	1.0	0.8	0.7	0.6	0.5	0.4
19.0	85.0	67.6	53.7	42.7	33.9	27.0	21.4	17.0	13.6	10.8	8.6	6.8	5.5	4.4	3.5	2.8	2.2	1.8	1.4	1.2	0.9	0.8	0.6	0.5	0.4	0.4
20.0	79.0	62.8	49.9	39.7	31.5	25.1	19.9	15.8	12.6	10.0	8.0	6.4	5.1	4.1	3.2	2.6	2.1	1.7	1.3	1.1	0.9	0.7	0.6	0.5	0.4	0.3
21.0	73.5	58.4	46.4	36.9	29.3	23.3	18.5	14.7	11.7	9.3	7.4	5.9	4.7	3.8	3.0	2.4	1.9	1.6	1.3	1.0	0.8	0.7	0.6	0.5	0.4	0.3
22.0	68.4	54.3	43.2	34.3	27.3	21.7	17.2	13.7	10.9	8.7	6.9	5.5	4.4	3.5	2.8	2.3	1.8	1.5	1.2	1.0	0.8	0.6	0.5	0.4	0.4	0.3
23.0	63.6	50.6	40.2	31.9	25.4	20.2	16.1	12.8	10.2	8.1	6.5	5.1	4.1	3.3	2.6	2.1	1.7	1.4	1.1	0.9	0.7	0.6	0.5	0.4	0.4	0.3
24.0	59.2	47.1	37.4	29.7	23.6	18.8	15.0	11.9	9.5	7.5	6.0	4.8	3.8	3.1	2.5	2.0	1.6	1.3	1.0	0.8	0.7	0.6	0.5	0.4	0.3	0.3
25.0	55.2	43.9	34.9	27.7	22.0	17.5	13.9	11.1	8.8	7.0	5.6	4.5	3.6	2.9	2.3	1.8	1.5	1.2	1.0	0.8	0.6	0.5	0.4	0.4	0.3	0.3

Table 4.3. Historical pH and temperature values for effluent and upstream quality at three sites (based on data for 1983-1985).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
City of Boulder												
temperature												
effluent	11.0	12.3	12.2	12.2	12.8	15.3	18.4	20.2	20.5	18.5	15.8	12.3
upstream	0.5	3.0	8.3	7.3	10.2	10.8	16.1	19.8	16.4	7.8	4.6	0.0
pH												
effluent	7.2	6.8	7.0	6.7	6.9	7.3	7.3	7.1	6.9	6.9	6.9	6.7
upstream	7.3	7.6	8.1	8.6	7.8	7.7	7.7	8.2	8.0	7.9	8.4	7.2
Englewood Joint-use												
temperature												
effluent	14	13	14	16	17	19	20	21	21	19	17	15
upstream	1.5	3.4	5.4	8.0	11.2	14.8	18.5	19.2	15.5	10.4	4.7	1.4
pH												
effluent	6.9	6.9	6.9	7.0	6.9	6.9	7.0	7.0	7.0	7.0	7.0	7.0
upstream	7.8	7.8	7.9	8.0	7.8	7.8	7.8	7.9	7.9	7.9	7.8	7.8
Fort Collins WWTF1												
temperature												
effluent	10.1	10.4	11.4	12.6	14.1	15.7	17.7	18.6	17.8	16.2	13.4	11.4
upstream	1.4	4.2	8.2	10.5	13.7	13.2	17.2	16.5	15.9	10.7	4.7	3.3
pH												
effluent	6.9-7.4	7.0-7.5	7.1-7.4	7.1-7.4	7.1-7.4	7.1-7.3	7.0-7.4	7.0-7.3	7.0-7.3	6.9-7.3	7.0-7.5	7.1-7.4
upstream	7.8	7.8	8.1	7.7	7.6	7.4	7.7	7.9	8.0	8.0	7.8	7.8

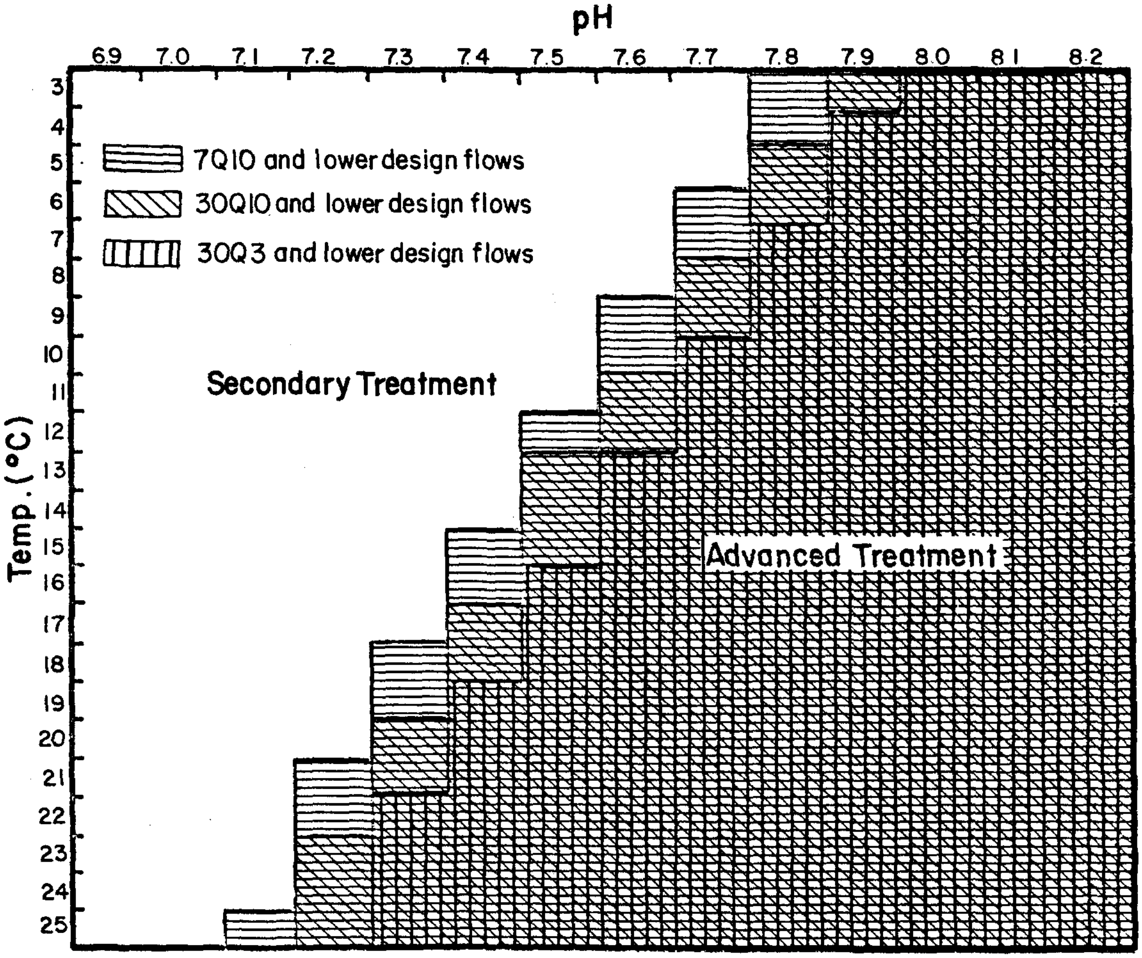


Figure 4.1 Ammonia treatment requirements for Englewood based on chronic design flows and a chronic instream ammonia standard of 0.06 mg/l-N.

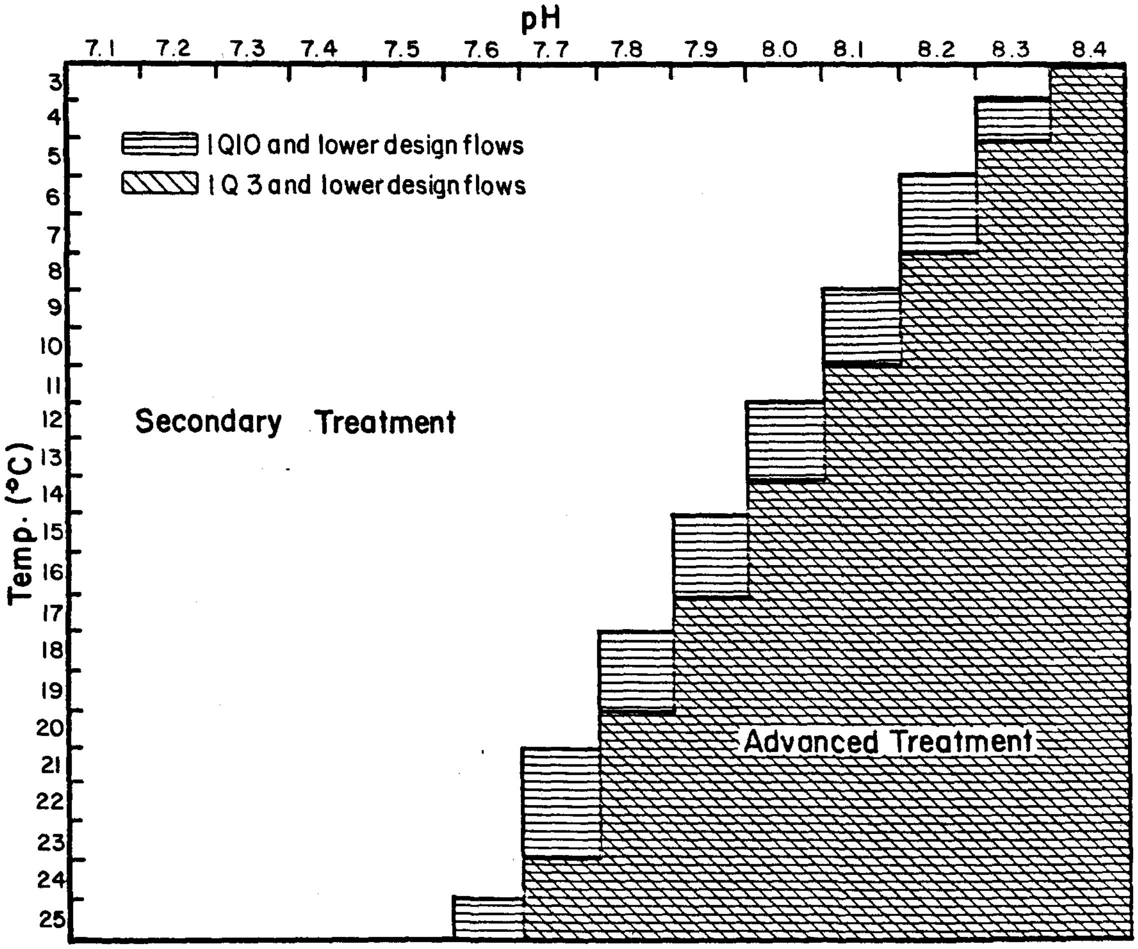


Figure 4.2 Ammonia treatment requirements for Englewood based on acute design flows and an acute instream ammonia standard of 0.20 mg/l-N.

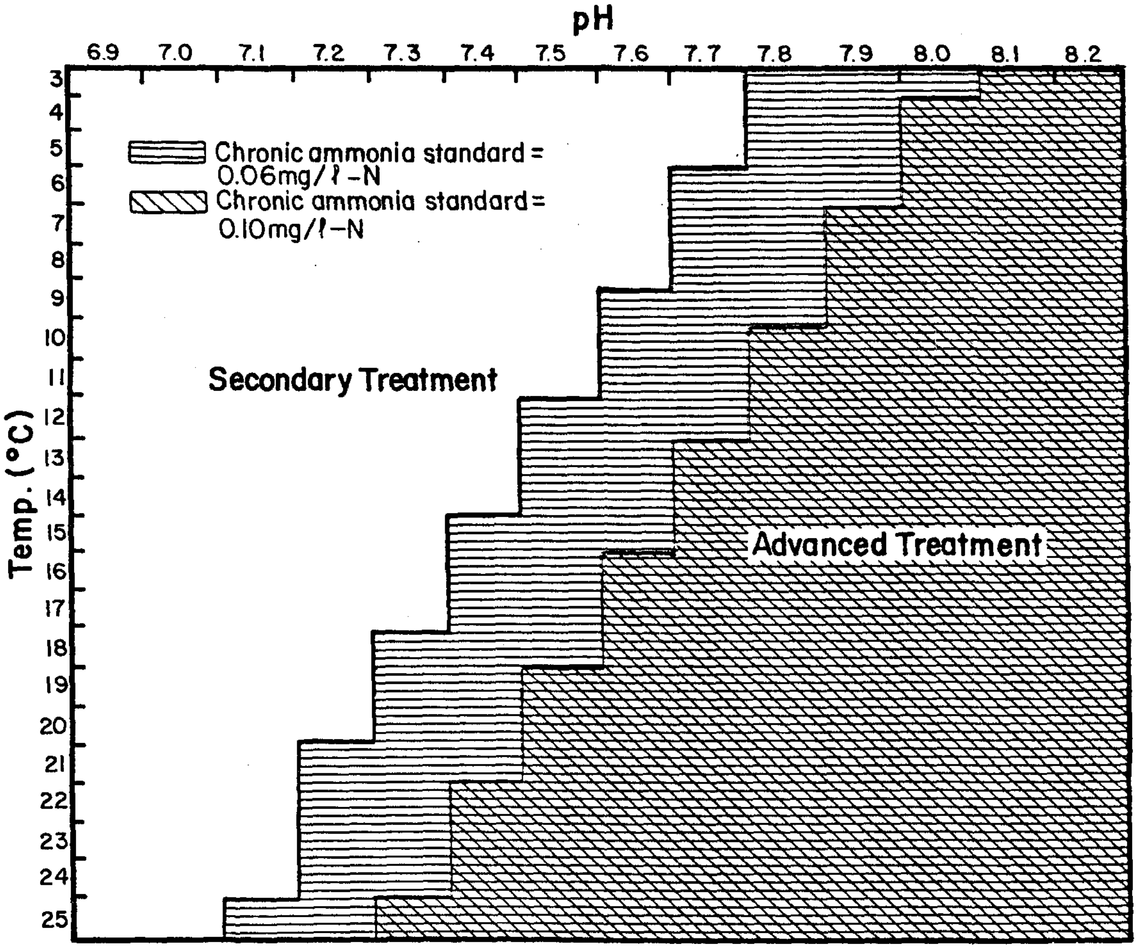


Figure 4.3 Ammonia treatment requirements for Englewood based on the 7Q10 design flow and chronic instream ammonia standards of 0.06 and 0.10 mg/l-N.

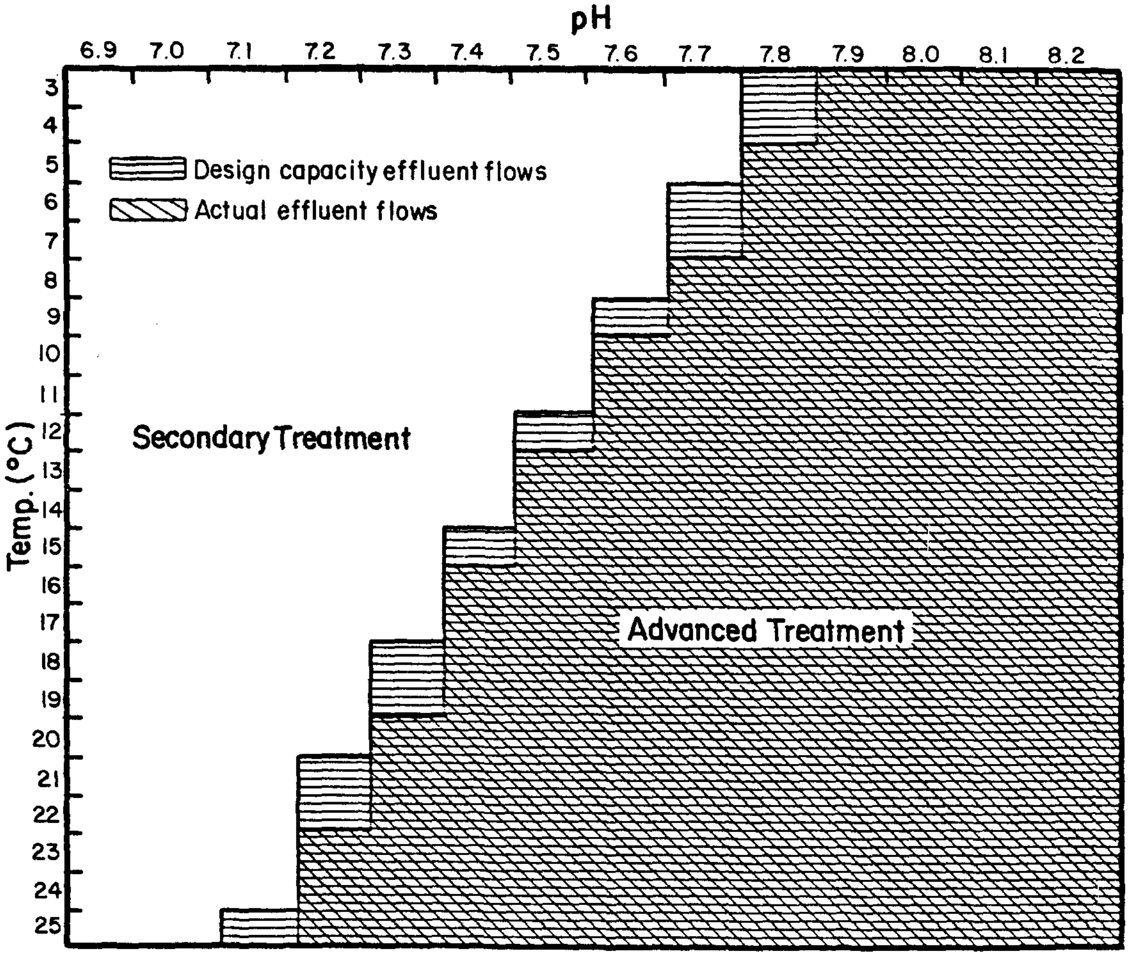


Figure 4.4 Ammonia treatment requirements for Englewood based on the 7Q10 design flow, a chronic instream ammonia standard of 0.06 mg/l-N, and effluent flows based on design capacity and actual historical use.

treatment only is required. The area shaded with the first pattern includes any pH-temperature conditions that would require advanced treatment, if limits were based on a design flow equal to the 7Q10 or less. For example, at Englewood given the use of the 7Q10 flow of 28 cfs and a temperature of 15°C, advanced treatment would be required at any pH of 7.4 or more. The area overlain with the second pattern includes conditions that would require advanced treatment if limits were based on the 30Q10 design flow. The area shaded with all three patterns includes those conditions that would require advanced treatment if limits were based on the 30Q3 design flow.

Savings in advanced treatment requirements is evidenced by the areas of the shaded boxes within the matrix. The larger the box, the greater the savings netted by the use of a higher design flow. The pH-temperature matrices show that advanced treatment requirements are highly variable with different pH-temperature conditions. In many cases, it appears that acute or chronic design flow is a less critical factor than pH. A comparison of the chronic flows at Englewood in Figure 4.1 provides a good example of this. Given a temperature of 15°C, advanced treatment would be triggered at pH 7.4 for a 7Q10 flow. Changing the design flow to a 30Q10 would shift the conditions for advanced treatment over one-tenth of a pH unit, to 7.5 or higher. A 30Q3 flow would require advanced treatment at pH 7.6 or more. Thus, increasing the design flow from the 7Q10 to the 30Q3, by 89 percent, shifts the conditions for advanced treatment requirements over by only two-tenths of a pH unit (3 percent).

Temperature also plays an important role in defining treatment requirements. Given a pH of 7.4 at Englewood, advanced treatment would be required at temperatures of 15°C or higher using a 7Q10 design flow. Changing the flow to a 30Q10 would shift the requirement for advanced treatment up to temperatures of 17°C or higher. A 30Q3 flow would shift the requirement up to 19°C. The total change in temperature conditions requiring advanced treatment achieved by increasing the design flow from a 7Q10 to a 30Q3, would be 4°C.

A comparison of two acute design flows (1Q10 and 1Q3) at Englewood also show minor savings in advanced treatment requirements with an increase in the design flow. The matrices of effluent limits based on chronic and acute design flows at Boulder, Longmont, and Fort Collins show similar results. Changes in the chronic design flow have a minor effect on treatment requirements relative to the effect of pH and temperature.

The effect of using a chronic instream un-ionized ammonia standard of 0.10 versus 0.06 mg/l-N in the effluent analysis are shown in Figure 4.3. Advanced treatment requirements are shifted over an average of about two-tenths of a pH unit, and up 2-4°C when a standard of 0.10 mg/l-N is used, rather than 0.06. This same effect occurs at the other sites as seen by a comparison of the Tables in Appendix B. Effluent limits based on an instream standard of 0.08 mg/l-N can be interpolated between the limits based on 0.06 and 0.10 mg/l-N. The effect of changing the effluent flow value from design capacity rating to actual flows at Englewood is shown in Figure 4.4. A 21 percent decrease in effluent flow produced relatively minor savings in advanced treatment requirements.

COPPER

Equation Used to Determine Effluent Limits

The analysis of a conservative element, such as copper, is included in this study to examine the relationship between design flows and effluent limits more directly than the un-ionized ammonia analysis permits. For the analysis of copper, a simple mass balance equation was used (Interim Report, 1986). Solving the equation for the permit limit gives the following:

$$C_E = \frac{(C_D)(Q_D) - (Q_U)(C_U)}{Q_E}$$

where C_E = effluent permit limit

C_D = downstream concentration (water quality criteria)

C_U = upstream ambient concentration

Q_U = upstream flow (design flow)

Q_D = downstream flow ($Q_U + Q_E$)

Q_E = effluent discharge

For this analysis, a single water quality criteria for copper was arbitrarily chosen as 0.01 mg/l. This value is based on Class 1 cold and warm-water requirements for alkalinity of 100-300 mg/l as found in current water quality criteria documents of Colorado (Colorado WQCC, 1984). The value used for upstream copper concentration was arbitrarily chosen as zero since instream copper data are limited and also to reduce the influence of other factors on the analysis. Effluent discharge values were generally taken as design capacities, although a few tests were made with actual discharges for comparison.

Results of Copper Effluent Limit Analysis

The results of the copper effluent limit analysis are presented in three tables. The first table (Table 4.4) gives theoretical effluent limits for copper based on five different annual design flows (1Q10, 7Q10, 1Q3, 30Q3, and 30Q10). A change from the 1Q10 to the 30Q3 chronic design flow at Englewood (89 percent increase) provides a 50 percent increase in the copper effluent limit. The effect of changing the acute design flow from a 1Q10 to

Table 4.4. Theoretical copper effluent limits based on five different annual flows.

Site	Effluent limit				
	1Q10	7Q10	1Q3	30Q10	30Q3
Englewood					
(mg/l)	0.023	0.026	0.029	0.030	0.039
(lbs/day)	5.5	6.0	6.8	7.0	9.2
Boulder					
(mg/l)	0.012	0.013	0.014	0.016	0.018
(lbs/day)	1.6	1.7	1.8	2.1	2.7
Longmont					
(mg/l)	0.016	0.017	0.018	0.02	0.024
(lbs/day)	1.5	1.6	1.8	1.9	2.4
Fort Collins					
(mg/l)	0.012	0.013	0.013	0.013	0.016
(lbs/day)	0.70	0.76	0.78	0.76	0.96

a 1Q3 (46 percent increase) is a 26 percent increase in the copper effluent limit. Similar results are given for the other sites.

Theoretical copper effluent limits based on monthly 7Q10 design flows are given in Table 4.5. Effluent limits at Englewood range from a minimum of 0.028 mg/l in September and October to a maximum of 0.053 mg/l in May. In this example, an increase in monthly 7Q10 flows of 141 percent produced an increase in effluent limits of 89 percent.

In Table 4.6, total allowable copper loads are compared for monthly versus annual 7Q10 design flows. The use of monthly 7Q10 design flows at Englewood produced a 31 percent increase in the total allowable load over the annual load. The increase in allowable loads resulting from the use of monthly design flows ranged from 31-80 percent over the four sites analyzed.

Table 4.5. Theoretical copper effluent limits based on monthly 7Q10 flows.

Site	Effluent limit											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Englewood												
(mg/l)	0.033	0.033	0.034	0.034	0.053	0.043	0.045	0.040	0.028	0.028	0.035	0.035
(lbs/day)	7.7	7.7	7.9	7.9	12.4	10.0	10.5	9.3	6.5	6.5	8.2	8.2
(lbs/month)	237	221	248	237	381	303	324	289	194	201	248	248
Boulder												
(mg/l)	0.014	0.017	0.017	0.018	0.022	0.034	0.036	0.025	0.021	0.016	0.015	0.018
(lbs/day)	1.9	2.2	2.3	2.3	2.8	4.4	4.8	3.2	2.8	2.0	2.0	2.3
(lbs/month)	59	61	70	70	87	133	147	100	83	64	60	72
Longmont												
(mg/l)	0.018	0.019	0.019	0.019	0.024	0.057	0.052	0.040	0.027	0.022	0.022	0.021
(lbs/day)	1.8	1.9	1.9	1.8	2.4	5.5	5.0	3.9	2.6	2.1	2.1	2.0
(lbs/month)	55	53	58	55	73	164	157	120	79	65	63	62
Fort Collins												
(mg/l)	0.013	0.013	0.014	0.013	0.014	0.072	0.060	0.026	0.015	0.013	0.013	0.013
(lbs/day)	0.76	0.76	0.82	0.76	0.82	4.20	3.50	1.52	0.87	0.76	0.76	0.76
(lbs/month)	24	22	25	23	25	127	109	48	26	24	23	24

Table 4.6. Comparison of theoretical allowable copper loads based on monthly and annual 7Q10 flows.

Site	Total lbs. of allowable copper/yr Monthly 7Q10	 Annual 7Q10	Percent Increase*
Englewood	3130	2173	31
Boulder	1006	641	57
Longmont	1003	588	71
Fort Collins	498	278	80

* Percent increase = ((monthly) - (annual) x 100)/ annual

CHAPTER 5 - CONCLUSIONS

METHODOLOGIES OF LOW-FLOW ANALYSIS

Period of Record

The period of record for frequency/duration analysis that has been recommended in the literature is 30 years of daily flows. Periods of record as short as 10 years may also be used for frequency/duration analysis, but could introduce larger errors. Because the data set for biologically-based analysis is larger, using all the flow data instead of the annual low flows, a period of record shorter than 20 or 30 years can be used to produce results with good confidence. Two major problems limit the length of available data sets - man-induced changes in the flow regime cause non-homogeneities and records at many gaging stations close to discharges are often short. To avoid problems with non-homogeneities and short data records it is recommended that 10 years of the most recent daily flow data available be used to calculate design flows and that the design flow values be updated every five years with NPDES permit renewals.

Extension of Flow Records and Predictions at Ungaged Sites

Two methods were applied to extend short periods of record or predict flows at ungaged sites - regression analysis and a water balance procedure. Other methods may also be appropriate. The use of one method over the other to generate flow records at the point of interest is both site and data specific. If there are a number of diversions, unmeasured tributaries and interaction with groundwater, water balance methods may be inappropriate, as was the case for estimating flow at the Denver STP outfall. Regression analysis can be quite useful if long periods of record exist nearby and there is a short period of record at the site to verify the models. However, when there is a choice of one model over another and different measures of goodness of fit appear equivalent then reasonableness of the model at a zero upstream flow condition should prevail in the choice of the most appropriate model.

Climatic Year

The climatic year (April 1-March 31) rather than the water year is the recommended period for frequency/duration analysis of low flows. The climatic year is used because it does not usually break up the low-flow period. In some cases where low flows occur in March or April, a different period of analysis may be more appropriate.

Frequency Analysis

There are a number of drawbacks to the use of mathematically defined frequency/duration statistics to calculate design flows. First, the estimate of a distribution function that fits low-flow data is difficult. The log-Pearson Type III distribution has been applied widely by the U.S. Geological Survey and the U.S. EPA in both flood and low-flow frequency analysis. It was used in this study to maintain consistency with prevailing practice. However, the results of this study have shown that the log-Pearson Type III distribution did not fit annual low-flow data at any of the sites tested and fit monthly data at only a few of the sites. Normal or log-normal distributions were more appropriate in a number of cases. It should be noted that for every site selected in this study, the 7Q10 determined using the normal distribution was less than the 7Q10 using the Log-Pearson Type III distribution (Table A5.9). No one distribution was adequate to cover all the sites for both annual and monthly flows. The use of an incorrect distribution function to analyze the flow data can introduce significant errors, but it may require extensive statistical analysis to avoid such problems.

Another source of error in frequency analysis is the violation of necessary statistical assumptions of randomness and independence of events. These assumptions are often violated by serially correlated annual or monthly low flows. Errors in parameter estimates may also affect the analysis. As an example, the frequency factor used in the log-Pearson Type III equation may be improved and based on a combination of the regionalized and station skews of low-flow data as in the case when estimating skew coefficients for distributions of flood events. However, regionalized skews have not been defined for low flows in the state of Colorado. This potential source of error has not been addressed previously, but could have a significant effect on the outcome of low-flow analysis. Estimates of sample means and variances may also introduce additional errors due to lack of data.

The graphical method of frequency analysis may be a viable alternative to the mathematical method because it eliminates some of the problems just described. No assumption as to a theoretical distribution function and no parameter estimates are required for the graphical method. However, there remain two major drawbacks to frequency statistic design flows. The first is that frequency/duration flows do not provide equal levels of protection from one site to another. As illustrated in this and other studies, the number of one day excursions below a given flow statistic, like the 7Q10, may vary by a factor of two to three from stream to stream, even along the Front Range in Colorado. In addition, frequency statistics do not relate directly to aquatic life criteria because they are based on the extreme low flow event for each year and do not account for any other low flows occurring during that same year.

U.S. EPA Biologically-Based Design Flows

The biologically-based method is an empirical, distribution-free approach to calculating design flows. The method is based on the actual historical flow record rather than on flows predicted by a statistical distribution. Being an empirical method utilizing only past flows, the biologically-based method does not require the stringent assumptions that the data has a specific distribution, that the parameters of the distribution such as the skew can be estimated with a small sample size, and that independence exists and correlation does not exist.

Biologically-based design flows relate to aquatic life criteria more directly than frequency/duration statistics. The reason for this is that biologically-based analysis considers all flows that fall below a given threshold level, whereas frequency/duration analysis is based on the extreme low-flow event for each year. Biologically-based analysis may be used to define design flows of acute or chronic durations that will occur at given allowable frequencies. The criteria for allowable duration and frequency recommended by the U.S. EPA are 1-day for acute and 4-day for chronic durations, and a frequency of once in three years. However, site specific conditions may be used to justify other criteria (e.g. longer chronic durations or greater frequencies of occurrence). Implementation of the biologically-based approach on an annual basis is relatively simple with existing programs developed by the U.S. EPA and STORET data files. The application of this analysis to monthly or seasonal design flows, however, will require some adaptation of existing programs.

Reliability of Low-Flow Analysis

Major sources of error in low-flow analysis include: inaccurate gage measurements, insufficient data (short record or long distance from site), non-homogeneous data, violations of assumptions in statistical analysis, and poor fits to probability distributions. These errors were not quantified, but may be significant for low-flow analysis.

Although all flow data used were from USGS gaging stations with appropriate rating of the quality of data, these ratings were based on all the data and not just low flows . Unless the flows are measured at some sort of control device, a spillway or weir, the low flow measures will be very imprecise and in many cases not measured but estimated. Conventional gaging techniques (depth of flow and a rating curve) without a control structure probably cannot measure flows accurately below 10 cfs and certainly cannot measure flows to the nearest tenth of a cfs.

FLOW DATA ANALYSIS

Monthly and Seasonal Flows

Monthly and seasonal design flows have been applied in a number of states to more fully utilize stream assimilative capacities. A major issue that has received little attention thus far is the significant increase in the number of excursions that occur below monthly or seasonal frequency statistic flows than below annual flows. This increase was well evidenced by the results of this study. The implication of this analysis is that a more restrictive monthly flow statistic is required to provide a comparable level of protection to that provided by a given annual statistic. As an example, it was shown that a comparable level of risk for an annual 7Q10 is defined statistically by a monthly 7Q115. However, a comparable level of risk may not be appropriate. It makes more sense to define an allowable frequency of excursions occurring in each month or season and choose monthly or seasonal flows to achieve those criteria. The allowable number of excursions could vary over the year to provide a high level of protection during critical seasons for aquatic life in the same way that seasonal standards have been applied. Greater use of assimilative capacity and more excursions could be allowed during non-critical periods.

A new technique was developed in this study to deal with the calculation of moving averages for monthly design flows. The technique, termed an overlapping procedure, is used to eliminate bias of the analysis toward the middle values of the month. In this study, overlapping was used only to calculate monthly frequency statistic flows, but could also be applied to biologically-based or excursion analysis. Use of the overlapping procedure complicates the analysis, but it should be recognized that without overlapping a bias is introduced. This bias becomes more important as the duration of the moving averages increases. The results of this study showed that the bias tended to produce higher monthly frequency statistic flows without the overlapping procedure.

EFFLUENT LIMIT ANALYSIS

Ammonia

The concentrations of ammonia used in this project were based upon existing criteria or recommendations by the U.S. EPA and were not subject to analysis as to the adequacy or appropriateness of the criteria to affect existing riverine biology. Un-ionized ammonia was chosen because of its known impact on fish, because it is not conservative and is in the effluent of every sewage outfall. Problems did arise, however, due to the dependence of un-ionized ammonia concentrations on temperature and pH. This dependence was so large as to make the assessment of the relationship of design flow, effluent load, and downstream concentrations very difficult to present. On one hand, for a given combination of pH and temperature, regardless of the dilution flow available, advanced treatment processes would be required. On the other hand, a slight decrease in temperature and/or pH would negate treatment beyond secondary.

It was found using Englewood flow and water quality data that during low flow excursions the calculated concentrations of un-ionized ammonia varied from a low of 0.018 mg/l for a flow of 53 cfs and a high of 0.074 mg/l for a flow of 28 cfs. There was a question whether there could be a relationship between duration of excursions, concentration of un-ionized ammonia and the flow statistic. However, using the limited data base a relationship could not be found. This was due in part to the poor water quality data available and the fact that the pH and temperature have a more dominant role in determining the downstream un-ionized ammonia concentration than dilution effects; probably only more conservative variables such as copper would show this effect.

Copper

Copper was chosen to be used as an example illustrating the relationship between design flows and the concentration of a conservative water quality variable. It is a heavy metal, can be toxic, can be found in sewage effluents and there are criteria associated with it. The increased loading into streams that resulted in the analysis did not take into account the possibility that it could settle out downstream.

It was found that changing the design flows could affect the allowable copper effluent concentrations significantly. A 26 percent increase in the effluent concentration is allowed if the design flow were changed from a 1Q10 to a 1Q3 at Englewood. Using a monthly 7Q10 versus an annual 7Q10 at Englewood allowed an increase of 31 percent of the total annual discharge of copper.

SELECTION OF APPROPRIATE DESIGN FLOWS FOR DISCHARGE PERMITTING

The criteria for the selection of appropriate design flows in the state of Colorado are based on the requirements of the most sensitive water use, which is aquatic life in most cases. Economic implications of various design flows may temper the selection, but current water quality regulations require that priority be given to the maintenance of existing instream uses. To protect aquatic life, the U.S. EPA has recommended that dual design flows be used to reflect acute and chronic conditions, and has recommended 1-day for acute and 4-day or 30-day for chronic. The recommended allowable frequency of occurrence is once in every three years. Alternative duration and frequency criteria may be justified as long as instream uses are protected.

Given a set of duration and frequency criteria, the selection of annual design flows is a relatively straightforward process. Historical low-flow data can be evaluated by either the biologically-based method or by excursion analysis to define flows that meet the criteria. Frequency/duration statistics can be used to approximate the flow values defined by this analysis at a given site, but do not provide consistent levels of protection from one stream to another.

In this study, it was found that the design flows meeting the criteria recommended by the U.S. EPA were the 1Q10 for acute flows and 7Q10 or 7Q15 for chronic flows. These design flows are very restrictive and provide no relief for dischargers from current limits. However, based on the recommended criteria, these flows maintain the required levels of protection for aquatic life. If the economic implications of such stringent design flows warrant a change, then the first factor to adjust must be the criteria. If the allowable frequency were switched to once every two years or if the chronic duration were switched from 4-day to 30-day, the effect on the design flow could be significant.

Monthly and seasonal design flows can be used effectively to increase the use of assimilative capacity and still maintain existing instream uses. The application of monthly or seasonal design flows will require further research in a number of areas, including the adaptation of biologically-based analysis and the definition of allowable excursions on a monthly or seasonal basis. It is recommended that seasonal variations in water quality and effluent quality also be reflected in the calculation of seasonal effluent limits. The choice of whether to use monthly or seasonal design flows may be a compromise between increased complexity and greater utilization of assimilative capacity. The results of this study have shown that the differences between annual and monthly design flows are much greater than between annual and seasonal design flows. The use of monthly design flows could result in substantially higher permit limits than seasonal flows, depending on the number of flow excursions allowed. The ability of dischargers to adjust their treatment processes on a monthly basis and the increased complexity of implementation, however, may restrict the use of monthly limits.

The selection of design flows for use in discharge permitting in the state of Colorado is a multi-million dollar issue. A number of the municipalities throughout the state currently may face advanced treatment requirements to achieve ammonia effluent limits based on annual 7Q10 design flows. Alternatives to annual 7Q10 have been analyzed with respect to flow magnitude, level of protection, and potential impact on dischargers. The choice of acute and chronic design flows must take these factors into account as well as the biological requirements of aquatic life communities reflected in instream water quality criteria.

It should be noted that basing a pollution control program on the number of streamflow excursions is not the same as the number of water quality excursions. If a flow below the 1Q3 flow were to occur on a specific day, it does not necessarily follow that an instream standard is violated. In fact, in the case of un-ionized ammonia, the combination of pH and temperature must also be above threshold values before a standard is violated. The sensitivity of the concentration of un-ionized ammonia to these variables is so strong that in many cases the instream flow has little effect on whether or not the standard is violated. Until a more quantitative method is available to account for all the factors that affect downstream water quality, a given design flow may be used as an indicator for pollution control rather than an indication that a standard has been violated.

It is worthwhile to note that the analyses presented in this report give very good estimates of the magnitude and frequency of low-flow events for the respective municipalities and since much of the uncertainty of these estimates are diminished, it may be prudent to reassess other factors which include the frequency distributions of the upstream and effluent un-ionized ammonia concentrations. Under the existing institutional framework of regulation and enforcement using only Englewood data, if the ammonia standard (un-ionized) were enforced at 0.02 mg/l or 0.06 mg/l, many communities in the state will be looking at AWT at least part of the year.

RECOMMENDATIONS

The recommendations that follow are those of the authors only, based upon the interpretation of the hydrologic data available and the analysis procedures utilized. Extrapolation of the recommendations beyond conditions experienced in the research or assuming that these recommendatiosn have the consensus support of the steering committee are both not justified at this time.

1) Follow the guidelines to compute the design flows given at the end of this chapter.
2) Develop a data base of actual conditions of pH, temperature, upstream ammonia concentration and downstream ammonia concentrations, particularly during periods of low-flow excursions to see if in fact water quality concentrations are: 1) violating the existing stream standard, and 2) diminishing downstream beneficial uses.
3) A monthly flow statistic may be quite beneficial as a means to better use stream assimilative capacity. However, intermittent AWT may be necessary during periods of low flows. If a monthly statistic is to be used, a monthly frequency criteria is recommended.
4) Both regression methods and mass balance are applicable for generating flow data, but the choice of one over the other will depend on the site

and data available. Regression methods appear quite adequate for predicting flow at a given outfall where limited streamflow data exist, but they are site and data specific requiring sound judgement by the practitioner.

5) Because mass balance for predicting flow at an outfall area was a problem due to lack of knowledge of the many small ungaged streams and the effect of groundwater it is recommended that more research be undertaken to estimate flows from ungaged watersheds, and return flows variation in time and space. Develop a data base specifically to estimate the relationship between groundwater flow and surface discharge during periods of low flow.

6) The present method of using streamflow excursions as a means of protecting downstream uses is not adequate in the case of un-ionized ammonia; pH, temperature and background ammonia must also be considered.

7) Develop better procedures for estimating the skew coefficient used in the statistical distribution for estimating low-flow statistics.

8) The Log-Pearson Type III distribution may not be the best distribution for frequency/duration analysis of low flows. Other distributions should also be investigated.

9) There may be sufficient justification to loosen the stream standard if the recommended flow statistics are used in the future for discharge permitting since there will be much fewer flow excursions.

10) The state must foresee future water quality problems and regulations and collect data and research to prove/disprove efficacy of the institutional procedures to ameliorate the water quality problems before the fact, not after.

RECOMMENDED GUIDELINES TO COMPUTE DESIGN FLOWS

The following is the procedure recommended to be used to estimate design flows in Colorado.

1) Select data set.

Use 10 years of the most recent daily flow data available, and update design flow values every five years with the permit renewal. This approach should reduce problems with non-homogeneity and short data records. If data are not available upstream of the point of discharge, use regression analysis or a water balance analysis to transfer flows to the correct location.

2) Define selection criteria.

First, determine whether the design flows are to be calculated on annual, monthly, or seasonal basis. Then define duration and frequency criteria to protect the most sensitive stream use, which is usually aquatic life.

a) Duration. Use two durations, 1-day for acute conditions and 4-day for chronic conditions as recommended by the U.S. EPA. A longer chronic duration may be justified if the flow and water quality conditions are relatively stable. Check coefficients of variation for low flows (flows less than the mean annual flow) and for major water quality variables to see if a longer duration is warranted. Relatively low C_v values, from 0.8 to 1.0 can be used to justify longer durations.

b) Frequency. Select an allowable frequency of excursions that will protect indigenous aquatic populations on a site-specific basis. The U.S. EPA has recommended once in three years to allow populations to recover fully after periods of stress. However, once in two years may be sufficient, depending on the characteristics of the species present.

Scientific rationale for the selection of a frequency other than once in three years should be provided. If monthly or seasonal flows are to be used, choose seasonally varying frequencies that reflect critical or non-critical conditions for aquatic life. During critical periods, use once in three years or a more restrictive frequency, and during non-critical periods use less restrictive frequencies. Account for cumulative effects of excursions during the course of several seasons within a year. The use of seasonal frequencies will require further research into acceptable levels of protection for particular uses.

3) Calculate design flows with the biologically-based method.

Use the program developed by the U.S. EPA for personal computers, or a similar version, along with STORET data files to calculate biologically-based design flows. Calculate flows on an annual, monthly, and seasonal basis initially to see which is the most effective. Monthly flows will provide for the greatest use of streams' assimilative capacity, but may be difficult to implement on such a short-term basis. Seasonal flows are recommended as a practical compromise between annual and monthly values. Seasonal variations in water quality and aquatic life requirements should also be incorporated into the analysis.

a) Annual flows. Use existing programs and annual frequency criteria.

b) Monthly flows. Adapt programs to a monthly basis and use monthly frequency criteria. If a moving average is used in the analysis, use the overlapping procedure to calculate averages for longer duration flows (i.e., 7-day or longer). Overlapping is not required for 1-day or 4-day durations.

c) Seasonal flows. Group months into low, high, and transition discharge seasons based on flow, water quality and effluent quality. First, make the initial selection of seasons based on flows. Use basic statistics (mean, median, and standard deviation) on moving averages of acute or chronic durations for each month to separate the seasons. Next, look at seasonal variations in the controlling water quality variables (e.g., pH and temperature for un-ionized ammonia levels). At this stage, also incorporate consideration of critical seasons (e.g., spawning periods) for aquatic life. Finally, check for large variations in effluent quality or quantity and adjust the selection of seasons if necessary. These last two steps may help to group transition flow months with high or low discharge seasons, or may actually change the designations of high or low given in the first stage of flow analysis. If water and effluent quality data are limited, base the selection of seasons on flows alone. Calculate seasonal design flows with programs adapted to a seasonal basis and with seasonal frequency criteria. Apply overlapping to longer duration flows, especially within short, one or two month long, seasons.

4) Evaluate potential sources of error. Consider potential errors based on the quality of the data set and the analysis. Factors to consider in the quality of data include: accuracy and completeness of the flow record, specifically during low-flow periods; the proximity of the gage to the point of interest; and the homogeneity of the data. Further research may be required to evaluate data errors quantitatively, but errors should be accounted for qualitatively at the least. Errors stemming from the analysis should be less when applying the biologically-based approach versus the frequency/duration methodology.

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APPENDIX A

FLOW DATA ANALYSIS

LIST OF TABLES FOR APPENDIX A

LIST OF FIGURES FOR APPENDIX A

APPENDIX A

Memorandum from Ben Harding of WBLA, Inc., Boulder, Colorado
To the City of Boulder; Re: Wasteload Allocation on Boulder Creek
Date: February 26, 1986

Estimation of Inflows and Dilutions Flows

We have estimated ungaged inflows to Boulder Creek above the 75th Street WWTP. Using those estimated inflows we have modeled Boulder Creek on a daily basis for the 12-year period 1959 through 1970. There are two major types of ungaged inflows to Boulder Creek; surface and subsurface. There are two sources of water; precipitation, including snowmelt, and return flows from agriculture. We have used three methods to estimate flows from the different sources. For ungaged surface inflows from precipitation, which come from the low elevation tributaries, we have used a correlation with Coal Creek. For return flows we have used an analysis of irrigation efficiency and flow routing. For excess flows not accounted for by these two methods, we have used a mass balance method based on measured diversions.

1. Ungaged Inflows

There are three ungaged inflows to the Boulder network. They are 1) Four Mile Creek; 2) the small, ungaged tributaries on the north side of Boulder Creek, including Bear Canyon Creek, Skunk Canyon Creek, Bluebell Canyon Creek, King's Gulch and Gregory Creek; 3) the small, ungaged tributaries on the south side of Boulder Creek, including Sunshine Canyon Creek, Goose Creek, Wonderland Creek, Twomile Canyon Creek and Fourmile Canyon Creek.

The daily inflows from these three sources were synthesized by multiplying the monthly Coal Creek gaged flow (in acre-feet) by the ratio of the particular tributary drainage area to the Coal Creek drainage area and then dividing by 59.4 to obtain an average daily flow in cfs.

In the network, the northern tributaries come into the system at the point of diversion of the Green Ditch. The southern tributaries come into the system above the confluence of South Boulder and Middle Boulder Creeks.

2. Return Flows

A monthly distribution of average agricultural return flows was calculated using the data presented in a report prepared by Rocky Mountain Consultants, Inc. entitled, Analysis of Transfer of North Boulder Farmers Ditch Shares. In this report, the authors calculate an average monthly return flow rate (using data from 1945 to 1965) attributable to 15.5 shares of the North Boulder Farmers Ditch. First, the return flow rates for each of five separate properties which all contribute to Boulder Creek are calculated using the Glover method. The resulting lag times for 95% of the return flow to reach Boulder Creek vary from 2 to 13 months, depending on the distance of each of these properties from the stream. The average return flow rates, in cfs., for all five properties combined are presented in Table 1:

Table 1.
Return Flows From the North Boulder Farmers Ditch (cfs)

Month	Flow
Jan.	0.05
Feb.	0.04
Mar.	0.02
Apr.	0.02
May	0.21
Jun.	0.49
Jul.	0.67
Aug.	0.44
Sep.	0.32
Oct.	0.18
Nov.	0.12
Dec.	0.08

The average annual diversion in this study was 559 acre feet. Over our 1959 to 1970 study period, the average annual diversion by the irrigation ditches which contribute return flows to Boulder Creek above 75th St. was Howard, Jones & Donelly, Anderson, Green, Smith & Goss, McCarty, Harden, Wellman-Nichols & Hahn and the North Boulder Farmers was subtracted in order to avoid counting the contribution of its return flow twice. The ratio of the two average annual diversions was used as a factor by which to multiply the return flow rates given above. The results in cfs. are presented in Table 2, below:

Table 2
Return Flows Above 75th Street From Agriculture (cfs)

Month	Flow
Jan	2
Feb	1
Mar	1
Apr	1
May	7
Jun	16
Jul	21
Aug	14
Sep	10
Oct	6
Nov	4
Dec	3

In terms of the model input data, the daily return flow rates were constant at the average monthly return flow rates. For example, from January 1 to January 31, the daily return flow rate was 2 cfs.

Table A1.1. Annual low flow frequency statistics at Littleton.

Recurrence interval (years)	Low flow (cfs) Duration 1-day	4-day	7-day	30-day
2	18	22	25	34
3	15	18	19	27
5	12	14	16	22
7	11	13	14	19
10	10	12	12	17
15	9	10	11	15

Table A1.2. Annual low flows for each year of record at Littleton.

Climatic year (4/1-3/31)	Low flow (cfs) Duration 1-day	4-day	7-day	30-day
1956	10	10	12	16
1957	7	8	8	9
1958	27	37	38	44
1959	18	20	21	25
1960	15	20	22	35
1961	16	24	25	29
1962	66	66	67	78
1963	10	11	11	21
1964	11	17	19	24
1965	14	16	16	18
1966	30	32	34	40
1967	15	19	20	25
1968	22	27	34	38
1969	14	15	17	26
1970	37	39	39	71
1971	48	53	53	62
1972	14	29	35	39
1973	30	39	40	41
1974	22	31	38	61
1975	18	24	32	43
1976	20	21	21	23
1977	16	21	29	43
1978	21	22	24	34
1979	12	13	13	29
1980	12	13	15	43
1981	21	23	23	30
1982	11	11	11	16
1983	17	18	19	23
1984	35	36	37	44
1985	23	31	46	83

Table A1.3. Annual low flow frequency statistics at Englewood.

Recurrence interval (years)	Low flow (cfs) Duration			
	1-day	4-day	7-day	30-day
2	43	48	52	61
3	35	40	43	53
5	30	33	35	44
7	27	30	32	41
10	24	26	28	36
15	22	25	26	34

Table A1.4. Annual low flows for each year of record at Englewood.

Climatic year (4/1-3/31)	Low flow (cfs) Duration			
	1-day	4-day	7-day	30-day
1956	27	33	35	38
1957	14	14	15	18
1958	54	68	71	78
1959	38	42	44	51
1960	27	31	33	49
1961	29	34	36	46
1962	92	114	119	133
1963	28	30	32	41
1964	19	22	26	44
1965	29	35	36	41
1966	60	65	67	85
1967	40	43	48	50
1968	48	54	60	87
1969	40	43	46	57
1970	66	69	73	99
1971	85	92	95	112
1972	47	65	66	72
1973	60	63	65	73
1974	44	55	64	104
1975	37	45	53	70
1976	38	40	44	51
1977	45	50	60	75
1978	45	47	50	58
1979	38	40	41	54
1980	43	47	51	64
1981	46	46	48	54
1982	38	40	43	54
1983	35	35	37	53
1984	73	75	76	87
1985	79	94	98	136

Table A1.5. Annual low flow frequency statistics at Henderson.

Recurrence interval (years)	Low flow (cfs) Duration 1-day	4-day	7-day	30-day
2	60	76	89	126
3	40	51	61	89
5	27	36	41	67
7	23	29	34	57
10	17	22	26	46
15	16	20	20	41

Table A1.6. Annual low flows for each year of record at Henderson.

Climatic year (4/1-3/31)	Low flows (cfs) Duration 1-day	4-day	7-day	30-day
1956	25	34	37	44
1957	9	10	10	28
1958	24	36	53	90
1959	52	53	53	59
1960	24	34	42	59
1961	60	62	62	67
1962	47	73	114	172
1963	9	11	12	22
1964	20	21	23	43
1965	22	34	41	72
1966	13	22	35	119
1967	60	86	110	155
1968	86	90	90	99
1969	74	77	80	88
1970	60	62	65	117
1971	143	176	250	329
1972	103	113	130	155
1973	97	116	133	192
1974	214	280	284	300
1975	124	143	147	162
1976	80	159	166	171
1977	85	104	113	151
1978	27	60	91	143
1979	52	57	73	173
1980	188	194	220	251
1981	105	116	130	172
1982	64	67	69	116
1983	81	100	105	140
1984	200	215	229	274
1985	252	270	287	337

Table A1.7. Annual low flow frequency statistics at Boulder.

Recurrence interval (years)	Low flow (cfs) Duration 1-day	4-day	7-day	30-day
2	12	15	16	24
3	10	12	13	20
5	7	9	10	17
7	6	8	10	15
10	5	7	8	14
15	5	6	8	13

Table A1.8. Annual low flows for each year of record at Boulder.

Climatic year (4/1-3/31)	Low flow (cfs) Duration 1-day	4-day	7-day	30-day
1960	21	23	24	29
1961	16	17	18	22
1962	35	39	46	56
1963	13	15	15	19
1964	6	7	9	19
1965	12	12	14	19
1966	19	25	24	27
1967	5	6	8	11
1968	4	8	9	29
1969	13	14	15	23
1970	19	22	26	34

Table A1.9. Annual low flow frequency statistics at Lyons.

Recurrence interval (years)	Low flow (cfs) Duration 1-day	4-day	7-day	30-day
2	3.6	5.2	5.9	7.8
3	2.2	3.3	3.8	6.0
5	1.4	2.1	2.4	4.7
7	1.1	1.6	1.9	4.2
10	0.8	1.2	1.3	3.6
15	0.6	0.8	0.9	3.2

Table A1.10. Annual low flows for each year of record at Lyons.

Climatic year (4/1-3/31)	Low flow (cfs) Duration 1-day	4-day	7-day	30-day
1956	0.5	1.4	2.0	3.7
1957	0.2	0.3	0.3	3.5
1958	0.7	2.7	2.8	4.3
1959	0.7	0.7	0.7	2.4
1960	2.6	2.8	3.0	6.0
1961	0.7	1.4	1.8	4.5
1962	7.8	11.8	13.1	14.8
1963	2.8	4.9	5.8	6.1
1964	0.7	0.9	0.9	2.1
1965	1.4	1.6	1.8	4.4
1966	4.1	4.3	4.8	7.6
1967	1.8	2.4	3.0	5.1
1968	7.1	7.7	7.8	10.5
1969	4.7	5.8	6.5	7.5
1970	3.8	5.1	5.5	7.5
1971	6.0	6.5	6.8	9.0
1972	4.0	5.8	9.5	10.4
1973	7.5	8.9	9.1	10.8
1974	3.5	4.8	5.4	7.9
1975	4.5	5.8	6.3	8.8
1976	4.6	6.8	7.6	8.8
1977	2.7	3.9	4.3	5.2
1978	3.8	8.0	8.3	9.4
1979	8.5	10.1	11.4	12.2
1980	16.0	18.3	18.6	19.9
1981	6.6	7.6	7.7	10.4
1982	2.5	5.1	6.7	8.7
1983	5.3	12.8	15.0	16.8
1984	14.0	15.5	16.3	18.7
1985	14.0	15.8	16.4	17.9

Table A1.11. Annual low flow frequency statistics at Longmont based on a regression of daily flows.

Recurrence interval (years)	Low flow (cfs) Duration 1-day	4-day	7-day	30-day
2	19	23	25	32
3	15	19	20	26
5	12	15	16	22
7	11	14	15	20
10	10	12	12	18
15	9	10	12	16

Table A1.12. Annual low flows for for each year of record at Longmont based on a regression of daily flows.

Climatic year (4/1-3/31)	Low flow (cfs) Duration 1-day	4-day	7-day	30-day
1956	7	8	9	11
1957	8	11	12	14
1958	10	19	39	40
1959	16	21	23	26
1960	7	7	8	23
1961	15	25	30	33
1962	26	39	46	60
1963	17	19	21	26
1964	10	12	13	18
1965	18	18	19	21
1966	23	24	26	38
1967	13	14	14	16
1968	11	13	14	36
1969	18	22	22	25
1970	15	17	18	28
1971	28	31	36	45
1972	26	29	30	34
1973	24	28	29	42
1974	24	37	39	48
1975	31	33	35	38
1976	15	22	23	30
1977	17	20	21	28
1978	23	24	24	26
1979	22	25	27	30
1980	39	42	46	73
1981	28	32	33	38
1982	23	24	25	29
1983	22	24	26	28
1984	36	39	40	48
1985	48	49	51	59

Table A1.13. Annual low flow frequency statistics at Longmont based on a regression of log-transformed daily flows.

Recurrence interval (years)	Low flow (cfs) Duration 1-day	4-day	7-day	30-day
2	21	24	26	31
3	17	20	21	26
5	14	17	18	22
7	13	15	16	20
10	12	13	14	19
15	10	13	13	17

Table A1.14. Annual low flows for for each year of record at Longmont based on a regression of log-transformed daily flows.

Climatic year (4/1-3/31)	Low flow (cfs) Duration 1-day	4-day	7-day	30-day
1956	11	11	12	15
1957	8	9	9	15
1958	10	18	32	37
1959	16	17	17	20
1960	10	11	11	24
1961	17	23	24	30
1962	43	44	46	57
1963	19	21	22	28
1964	13	15	15	18
1965	19	20	20	23
1966	24	27	28	36
1967	15	16	17	19
1968	15	16	17	34
1969	21	24	24	26
1970	17	19	21	28
1971	28	30	34	43
1972	27	30	32	35
1973	27	30	31	43
1974	26	38	40	42
1975	30	32	34	38
1976	17	25	25	32
1977	20	23	24	29
1978	23	24	24	26
1979	22	25	27	30
1980	39	42	46	73
1981	28	32	33	38
1982	23	24	25	29
1983	22	24	26	28
1984	38	40	42	48
1985	48	48	51	59

Table A1.15. Annual low flow frequency statistics at Longmont based on regressions of annual low flows.

Recurrence Interval (years)	Low flow (cfs) Duration 4-day	7-day	30-day
2	26	28	58
3	22	23	25
5	19	20	20
7	18	18	18
10	16	16	16
15	15	16	14

Table A1.16. Annual low flows for each year of record at Longmont based on regressions of annual low flows.

Climatic year (4/1-3/31)	Low flow (cfs) Duration 4-day	7-day	30-day
1956	11	11	11
1957	15	15	12
1958	29	38	48
1959	28	30	32
1960	16	16	28
1961	32	35	37
1962	35	36	41
1963	26	28	31
1964	16	15	12
1965	19	20	18
1966	20	21	26
1967	21	22	18
1968	19	20	24
1969	28	29	28
1970	19	20	23
1971	37	41	50
1972	31	32	37
1973	31	32	38
1974	38	41	56
1975	35	38	42
1976	28	29	33
1977	22	24	25
1978	23	23	22
1979	27	28	32
1980	37	41	65
1981	35	38	42
1982	23	25	31
1983	19	20	16
1984	38	41	47
1985	44	47	64

Table A1.17. Annual low flow frequency statistics for Platteville.

Recurrence interval (years)	Low flow (cfs) Duration 1-day	4-day	7-day	30-day
2	53	59	64	83
3	42	47	50	67
5	35	38	40	55
7	31	34	36	50
10	27	29	31	43
15	27	26	30	39

Table A1.18. Annual low flows for each year of record at Platteville.

Climatic year (4/1-3/31)	Low flow (cfs) Duration 1-day	4-day	7-day	30-day
1956	16	16	17	29
1957	24	26	26	34
1958	45	69	97	127
1959	64	65	71	85
1960	25	28	30	76
1961	57	81	88	100
1962	84	90	93	110
1963	56	60	64	82
1964	28	28	28	34
1965	36	38	40	48
1966	37	41	44	70
1967	42	43	45	50
1968	36	38	41	66
1969	56	67	67	75
1970	34	37	41	62
1971	90	99	110	131
1972	74	75	79	98
1973	70	77	78	103
1974	75	105	109	148
1975	81	92	99	113
1976	52	66	67	88
1977	44	46	52	68
1978	46	50	50	60
1979	61	61	64	87
1980	80	101	110	170
1981	80	93	97	113
1982	47	49	54	84
1983	32	36	40	44
1984	93	103	107	124
1985	125	129	133	168

Table A1.19. Annual low flow frequency statistics at Fort Collins.

Recurrence interval (years)	Low flow (cfs) Duration 1-day	4-day	7-day	30-day
2	1.9	2.2	2.4	4.8
3	1.5	1.8	2.0	2.9
5	1.2	1.5	1.6	2.0
7	1.0	1.4	1.5	1.6
10	0.9	1.3	1.4	1.4
15	0.8	1.2	1.2	1.2

Table A1.20. Annual low flows for each year of record at Fort Collins.

Climatic year (4/1-3/31)	Low flow (cfs) Duration 1-day	4-day	7-day	30-day
1977	1.6	1.6	1.7	2.0
1978	1.4	1.5	1.5	1.8
1979	1.3	1.3	1.4	2.8
1980	2.3	2.8	3.5	5.0
1981	2.7	2.8	2.9	3.3
1982	0.8	2.1	2.1	2.7
1983	1.4	1.6	1.9	9.9
1984	5.1	5.1	5.3	50.8
1985	4.3	5.2	5.5	45.9

Table A2.1. Monthly low flow frequency statistics at Englewood.

Month	7-day low flow (cfs) Recurrence Interval (years)				4-day low flow (cfs) Recurrence Interval (years)				1-day low flow (cfs) Recurrence Interval (years)			
	2	3	5	10	2	3	5	10	2	3	5	10
Jan	67	56	48	41	65	55	47	40	62	53	46	39
Feb	69	58	50	42	66	56	48	41	63	53	46	40
Mar	74	61	52	44	71	58	50	42	67	55	47	40
Apr	107	78	58	43	101	74	56	41	93	67	50	37
May	246	159	110	77	230	148	102	70	204	130	89	60
Jun	234	144	94	60	212	130	85	52	188	113	73	45
Jul	186	137	95	63	162	120	84	55	133	98	69	47
Aug	159	112	79	54	150	101	71	47	130	89	63	43
Sep	76	56	43	32	69	52	40	30	64	48	37	28
Oct	67	50	40	32	63	48	38	31	62	47	37	28
Nov	73	62	52	46	70	60	51	45	66	55	48	43
Dec	70	62	52	46	69	59	51	45	66	56	49	43

Table A2.2. Monthly low flow frequency statistics at Boulder.

Month	7-day low flow (cfs) Recurrence Interval (years) 2	3	5	10	4-day low flow (cfs) Recurrence Interval (years) 2	3	5	10	1-day low flow (cfs) Recurrence Interval (years) 2	3	5	10
Jan	25	19	15	11	24	18	14	10	18	14	10	8
Feb	33	26	20	16	31	24	19	15	24	18	14	11
Mar	49	37	27	18	48	36	26	18	40	29	21	14
Apr	57	41	29	19	52	36	25	16	46	30	19	11
May	83	57	41	28	76	52	37	26	66	43	29	19
Jun	94	77	66	58	87	73	62	55	72	58	48	40
Jul	95	83	74	64	85	74	66	58	68	62	54	50
Aug	55	47	41	36	50	45	38	35	47	42	36	33
Sep	31	30	28	27	27	25	24	23	23	21	20	18
Oct	27	24	18	14	24	20	15	10	22	18	14	10
Nov	35	25	18	13	31	22	16	12	29	20	14	10
Dec	40	31	24	19	35	28	22	18	33	26	21	16

Table A2.3. Monthly low flow frequency statistics at Longmont (from a regression of daily flows).

Month	7-day low flow (cfs) Recurrence Interval (years) 2	3	5	10	4-day low flow (cfs) Recurrence Interval (years) 2	3	5	10	1-day low flow (cfs) Recurrence Interval (years) 2	3	5	10
Jan	32	25	20	15	29	24	19	14	28	22	17	12
Feb	34	32	22	17	30	26	22	18	28	22	18	14
Mar	32	26	21	17	30	25	21	17	30	24	19	15
Apr	34	26	20	16	32	24	20	16	30	22	17	13
May	74	51	36	26	43	35	29	25	64	43	30	21
Jun	203	151	115	84	94	74	61	49	183	136	104	75
Jul	125	88	88	76	75	63	56	49	113	92	77	64
Aug	85	63	63	54	57	51	47	43	79	66	56	47
Sep	59	40	40	31	46	40	35	28	54	45	37	30
Oct	49	29	29	21	39	32	26	20	46	35	27	19
Nov	44	28	28	21	37	31	26	20	40	31	24	18
Dec	36	24	24	19	33	28	23	19	31	25	20	16

Table A2.4. Monthly low flow frequency statistics at Longmont (from a regression of log-transformed daily flows).

Month	7-day low flow (cfs) Recurrence Interval (years)				4-day low flow (cfs) Recurrence Interval (years)				1-day low flow (cfs) Recurrence Interval (years)			
	2	3	5	10	2	3	5	10	2	3	5	10
Jan	31	26	21	17	30	25	20	16	28	23	19	15
Feb	33	27	23	19	32	27	22	18	30	25	21	17
Mar	32	26	21	17	32	26	21	17	30	24	20	16
Apr	34	26	21	17	33	25	20	16	30	23	18	14
May	60	40	29	20	58	39	28	20	51	35	25	18
Jun	117	88	70	55	107	80	64	51	100	75	59	46
Jul	98	80	67	55	93	76	63	51	86	69	58	47
Aug	76	64	54	45	73	61	51	42	70	58	48	39
Sep	54	47	40	33	56	47	40	32	54	45	39	32
Oct	47	36	28	20	46	35	28	20	45	34	26	19
Nov	43	34	27	21	41	32	26	20	38	30	23	18
Dec	36	30	25	21	34	28	24	20	31	26	22	18

Table A2.5. Monthly low flow frequency statistics at Longmont (based on regressions of monthly low flows).

Month	7-day low flow (cfs) Recurrence Interval (years)				4-day low flow (cfs) Recurrence Interval (years)				1-day low flow (cfs) Recurrence Interval (years)			
	2	3	5	10	2	3	5	10	2	3	5	10
Jan	32	27	23	18	29	25	22	19	31	26	21	17
Feb	34	29	24	20	30	27	24	21	33	28	23	20
Mar	32	26	22	18	29	25	22	19	32	27	22	18
Apr	35	27	21	17	29	25	21	18	30	24	19	15
May	62	43	32	23	43	33	28	22	49	35	26	15
Jun	115	88	70	56	65	54	47	40	89	68	55	44
Jul	94	77	64	53	58	51	45	40	80	66	56	47
Aug	73	62	54	45	50	45	40	36	66	55	47	39
Sep	56	42	40	33	42	37	33	29	53	45	39	32
Oct	46	35	27	20	37	31	26	21	45	35	28	21
Nov	44	35	29	23	35	30	26	22	41	32	26	20
Dec	37	32	27	23	32	28	26	23	34	29	25	21

Table A2.6. Monthly low flow frequency statistics at Platteville.

Month	7-day low flow (cfs) Recurrence interval (years) 2	3	5	10	4-day low flow (cfs) Recurrence interval (years) 2	3	5	10	1-day low flow (cfs) Recurrence interval (years) 2	3	5	10
Jan	103	83	67	51	97	78	62	48	87	70	56	43
Feb	108	88	72	56	104	85	69	54	96	77	63	49
Mar	92	76	64	54	90	74	63	53	86	71	61	51
Apr	80	60	45	34	75	56	44	33	70	52	40	31
May	106	68	46	31	101	64	44	29	86	56	39	27
Jun	174	125	95	72	155	111	84	63	142	101	76	57
Jul	162	132	103	81	143	115	96	80	144	113	91	71
Aug	146	121	101	80	141	116	96	76	133	108	88	69
Sep	134	112	94	76	141	116	96	74	124	104	88	71
Oct	122	99	81	64	119	96	79	62	114	94	76	60
Nov	124	101	84	68	119	98	81	66	113	92	76	62
Dec	111	92	77	63	106	88	73	59	96	78	64	51

Table A2.7. Monthly low flow frequency statistics at Fort Collins.

Month	7-day low flow (cfs) Recurrence Interval (years)				4-day low flow (cfs) Recurrence Interval (years)				1-day low flow (cfs) Recurrence Interval (years)			
	2	3	5	10	2	3	5	10	2	3	5	10
Jan	4.5	3.2	1.8	1.4	3.8	2.4	1.7	1.4	3.3	2.1	1.5	1.2
Feb	5.0	3.0	2.0	1.4	4.7	3.1	1.9	1.3	4.4	2.9	1.8	1.3
Mar	5.0	3.4	2.2	1.7	4.4	3.0	2.2	1.7	3.9	2.6	1.9	1.5
Apr	6.4	3.6	2.2	1.4	5.7	3.2	2.0	1.3	4.9	2.8	1.8	1.2
May	31.3	10.9	4.5	1.8	23.0	7.9	3.3	1.3	14.5	5.3	1.8	0.8
Jun	152.5	80.8	47.7	28.2	128.6	83.3	57.7	39.6	82.9	34.0	15.4	6.5
Jul	45.4	33.2	26.7	22.5	32.0	23.8	19.5	16.8	9.8	7.2	4.7	3.6
Aug	21.6	14.4	10.3	7.4	14.9	9.7	6.8	4.8	5.7	4.2	2.7	2.1
Sep	6.9	4.5	3.1	2.1	4.9	3.4	2.6	1.9	2.9	2.0	1.5	1.1
Oct	3.9	2.8	1.9	1.5	3.6	2.5	1.8	1.3	3.4	2.5	1.9	1.4
Nov	7.2	4.0	2.4	1.4	6.6	3.8	2.3	1.4	5.5	3.4	2.2	1.5
Dec	4.0	2.7	1.9	1.4	3.7	2.5	1.8	1.4	3.4	2.4	1.8	1.4

Table A2.8. Monthly 1-day low flows for each year of record at Littleton.

Water year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1955	11	17	13	12	11	11	10	72	46	24	110	101
1956	16	19	22	14	13	18	16	123	107	36	17	8
1957	7	14	10	9	12	15	27	101	691	218	454	42
1958	39	47	46	35	40	38	101	328	242	94	28	24
1959	29	25	23	18	28	30	76	96	149	74	51	15
1960	38	35	33	29	28	42	340	330	206	104	16	19
1961	23	33	44	42	39	62	94	154	67	89	292	104
1962	154	238	79	66	100	74	143	122	166	106	48	20
1963	10	18	29	20	27	27	11	15	12	17	17	65
1964	19	32	32	20	15	28	51	132	60	97	47	21
1965	18	28	19	14	16	23	36	182	230	302	439	232
1966	123	55	39	33	40	30	32	81	59	52	57	35
1967	27	45	36	45	30	15	26	34	64	46	150	61
1968	22	55	35	30	34	34	37	90	81	90	162	68
1969	66	44	35	14	15	27	37	82	281	317	263	78
1970	72	147	112	95	54	58	204	1500	1140	444	131	64
1971	74	54	49	48	56	58	46	212	177	158	122	40
1972	31	28	32	40	38	14	30	63	74	95	80	43
1973	43	39	38	34	43	58	72	758	774	187	107	22
1974	68	63	49	60	51	135	164	167	74	52	43	18
1975	45	36	36	38	43	42	45	43	74	93	112	74
1976	20	20	22	39	34	46	48	51	40	171	130	43
1977	31	30	34	36	16	16	55	66	38	60	60	44
1978	25	21	21	25	29	30	29	34	18	91	91	36
1979	31	23	12	22	34	30	61	12	19	77	60	24
1980	27	24	21	31	55	51	54	1030	825	201	84	28
1981	22	23	32	25	26	21	13	45	33	43	45	49
1982	49	23	11	15	12	11	18	29	24	40	183	130
1983	63	22	19	18	17	66	97	672	1080	315	393	36
1984	35	45	49	42	78	79	163	556	500	133	87	63
1985	198	125	48	52	23	32	53	949	190	135	174	28

Table A2.9. Monthly 4-day low flows for each year of record at Littleton.

Water year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1955	11	18	13	12	12	12	10	79	48	30	239	103
1956	18	28	23	15	14	18	17	167	121	47	23	8
1957	8	14	12	9	14	17	34	167	793	512	431	44
1958	45	76	51	37	41	40	127	395	267	108	34	28
1959	33	25	24	20	32	32	81	110	145	94	61	20
1960	43	38	38	30	30	42	387	340	188	145	26	24
1961	29	39	46	44	41	66	94	157	83	184	336	114
1962	171	256	88	66	105	80	168	147	219	151	47	23
1963	11	24	30	24	29	27	17	21	22	19	19	78
1964	23	34	37	21	18	30	59	154	87	119	46	27
1965	20	30	21	16	17	29	39	196	264	364	466	247
1966	123	59	41	37	41	32	57	89	66	62	60	36
1967	29	48	39	47	27	19	27	46	65	53	173	49
1968	27	52	38	32	36	35	44	109	88	127	177	75
1969	68	46	40	15	20	30	39	88	332	392	304	76
1970	83	168	133	102	59	75	216	1593	1187	491	148	85
1971	80	61	53	53	59	61	59	228	192	197	183	39
1972	33	29	36	42	41	33	33	76	137	105	97	44
1973	44	45	39	39	45	59	91	782	769	264	180	31
1974	74	64	59	60	57	137	214	213	106	83	52	24
1975	49	38	41	38	43	45	48	95	101	232	175	78
1976	21	21	22	39	36	48	51	52	46	201	168	47
1977	35	39	37	39	21	30	66	112	41	65	81	45
1978	29	22	22	26	28	31	30	45	23	94	92	38
1979	32	24	13	22	34	34	102	13	30	120	73	29
1980	28	27	23	32	57	51	68	1245	845	273	98	30
1981	23	32	35	26	31	19	23	60	34	47	50	49
1982	49	25	11	15	12	11	18	35	41	52	224	172
1983	61	22	19	18	18	98	167	1191	1575	450	380	38
1984	36	47	51	43	79	81	165	761	559	128	416	115
1985	261	125	50	55	31	42	66	955	409	141	189	32

Table A2.10. Monthly 7-day low flows for each year of record at Littleton.

Water year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1955	12	19	14	13	13	12	11	82	53	36	234	105
1956	19	31	24	15	15	19	18	190	139	57	27	8
1957	8	15	12	10	13	17	32	189	831	601	441	48
1958	50	98	53	38	47	42	142	440	258	105	39	30
1959	37	25	24	21	31	34	82	132	145	110	58	22
1960	47	39	38	31	31	41	378	372	202	192	28	25
1961	29	42	50	46	43	68	97	177	94	163	348	125
1962	183	256	89	67	110	91	193	165	227	170	59	24
1963	11	23	32	26	30	28	21	24	25	22	27	82
1964	29	36	38	21	19	30	70	163	101	131	50	31
1965	20	31	22	16	17	31	45	222	280	413	483	265
1966	140	67	43	37	43	33	66	92	76	61	66	36
1967	32	50	40	46	28	20	28	57	68	61	176	64
1968	38	52	38	34	37	35	44	112	99	147	179	77
1969	71	46	40	17	20	31	39	87	405	407	294	80
1970	95	212	142	108	65	72	205	1647	1232	489	171	103
1971	83	67	53	54	62	62	68	250	228	256	189	50
1972	36	35	38	44	44	39	37	86	164	117	108	45
1973	45	46	40	40	48	61	97	709	776	342	215	38
1974	79	66	59	60	67	139	231	220	109	137	61	32
1975	55	42	43	40	43	46	51	114	123	416	207	95
1976	23	21	22	39	36	48	52	56	48	218	190	85
1977	46	42	40	42	29	30	65	122	44	61	97	48
1978	32	31	24	26	31	36	30	54	30	98	94	38
1979	33	24	13	22	35	36	103	15	111	182	76	33
1980	30	27	23	36	60	53	98	1418	997	353	123	30
1981	23	40	35	27	34	31	30	79	35	48	52	63
1982	49	26	12	15	14	11	20	43	65	105	257	190
1983	97	23	26	19	20	98	237	1312	1750	578	402	41
1984	37	45	51	52	84	92	165	1056	625	136	422	142
1985	325	165	122	59	53	46	95	976	497	224	222	33

Table A2.11. Monthly 7-day low flows (without overlapping) for each year of record at Littleton.

Water year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1955	12	22	14	13	13	12	12	88	68	36	312	105
1956	19	32	24	16	15	20	18	226	150	57	27	8
1957	8	16	12	10	16	17	44	447	831	602	568	48
1958	50	98	53	38	47	42	142	445	281	114	39	30
1959	37	25	26	21	33	34	123	141	183	110	88	22
1960	47	40	40	31	31	62	405	375	291	192	34	25
1961	32	42	56	46	43	68	113	247	99	186	348	125
1962	183	256	91	67	110	91	298	165	258	178	72	24
1963	11	27	32	26	31	29	24	26	25	23	54	82
1964	29	36	42	21	19	30	71	163	101	131	66	31
1965	20	33	22	16	18	31	45	222	427	413	483	265
1966	176	67	43	37	43	34	91	114	76	61	69	36
1967	32	50	40	49	32	20	35	57	89	61	176	78
1968	38	59	38	34	41	35	57	114	99	165	179	81
1969	75	47	40	18	28	32	39	662	405	407	330	90
1970	119	281	144	108	65	93	316	1647	1293	517	251	103
1971	83	67	53	54	62	63	68	250	233	256	189	50
1972	37	35	38	45	47	40	45	88	164	117	108	45
1973	48	47	40	42	48	61	106	2112	830	389	215	38
1974	79	66	59	60	67	139	262	220	109	137	61	32
1975	55	47	43	40	44	46	51	114	123	470	207	111
1976	23	21	22	39	36	48	52	78	48	218	213	85
1977	46	42	45	42	29	39	124	122	44	77	121	48
1978	32	32	24	26	36	36	31	54	30	98	103	38
1979	33	24	13	22	35	36	103	15	111	184	89	33
1980	30	27	23	36	60	53	98	1617	1258	448	123	32
1981	23	40	35	27	47	39	35	79	35	53	52	67
1982	49	26	12	16	16	11	20	43	65	105	257	190
1983	149	25	26	19	20	131	237	1312	1750	578	498	41
1984	37	48	51	52	84	93	171	1174	656	149	496	142
1985	643	277	122	75	55	87	224	1140	498	224	222	33

Table A2.12. Monthly 1-day low flows for each year of record at Englewood.

Water year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1955	23	41	36	36	36	32	33	107	57	27	155	123
1956	31	45	49	37	36	42	40	159	127	44	27	14
1957	19	40	35	32	35	39	54	205	1052	379	575	65
1958	77	97	84	69	67	66	182	479	304	114	42	38
1959	50	52	51	42	56	57	119	225	208	95	83	27
1960	74	69	64	58	66	105	434	444	253	132	33	29
1961	46	66	76	72	70	95	130	284	92	129	368	244
1962	262	318	150	116	159	129	248	187	202	136	62	30
1963	28	43	56	44	52	50	25	30	21	19	26	98
1964	36	56	63	48	45	52	87	165	76	110	76	29
1965	34	57	45	39	41	52	76	240	367	410	613	302
1966	168	106	73	67	81	60	66	103	68	62	74	46
1967	55	77	65	74	56	40	48	62	139	96	181	89
1968	54	95	81	78	82	80	87	144	103	106	195	98
1969	98	77	67	40	47	64	66	191	559	393	325	96
1970	106	244	190	156	107	114	330	1983	1464	579	198	93
1971	130	114	96	85	109	109	88	380	326	204	179	69
1972	64	69	73	80	70	47	60	91	139	130	106	61
1973	63	73	72	74	89	100	141	1292	1008	308	158	44
1974	103	112	82	109	106	213	245	285	106	81	62	37
1975	81	66	69	71	75	74	72	105	295	215	140	103
1976	38	46	66	77	69	71	73	118	78	200	167	88
1977	63	81	84	71	45	56	99	142	57	69	86	54
1978	45	56	53	53	59	49	46	55	38	109	100	47
1979	50	48	39	45	59	55	147	157	465	122	100	43
1980	51	60	75	77	107	84	114	1447	1048	270	123	49
1981	46	52	60	51	58	51	38	78	45	62	61	73
1982	77	51	54	54	40	38	35	57	51	73	228	189
1983	115	58	51	51	45	119	365	1110	1524	565	586	73
1984	74	97	108	96	134	145	300	918	643	253	332	174
1985	358	248	132	108	79	95	147	1207	303	287	226	57

Table A2.13. Monthly 4-day low flows for each year of record at Englewood.

Water year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1955	23	42	37	36	38	33	34	114	55	33	272	127
1956	34	55	50	37	37	43	41	195	140	55	32	14
1957	19	40	36	33	38	40	64	253	1171	672	521	68
1958	83	134	92	72	69	70	205	546	312	124	48	42
1959	54	53	52	45	61	59	122	237	175	117	83	31
1960	78	73	63	59	68	99	463	461	228	173	41	34
1961	51	71	78	74	72	99	129	324	114	218	412	258
1962	276	337	150	117	169	138	263	213	258	174	60	33
1963	30	46	58	47	54	49	31	36	31	22	26	103
1964	40	63	67	50	48	57	96	188	110	134	68	36
1965	35	60	47	42	43	57	78	259	403	472	663	313
1966	172	110	77	74	82	64	90	105	75	73	77	48
1967	58	79	68	76	52	43	51	75	131	111	202	80
1968	58	98	84	80	84	81	93	177	142	144	210	105
1969	101	78	70	43	51	67	69	175	620	483	346	99
1970	126	271	208	166	112	131	334	2088	1411	592	194	121
1971	138	122	105	92	113	110	108	398	338	262	225	71
1972	65	74	76	83	77	64	64	105	207	139	128	64
1973	63	77	74	78	90	109	162	1256	966	400	229	55
1974	112	115	97	109	115	219	294	285	144	117	70	45
1975	88	70	73	73	77	77	76	146	321	346	203	102
1976	40	48	68	77	72	73	77	115	89	231	198	92
1977	75	84	88	75	50	64	108	144	59	75	101	54
1978	47	56	56	58	58	50	46	70	45	113	102	48
1979	54	49	40	46	60	61	150	232	469	166	100	47
1980	52	64	81	80	109	93	128	1774	1030	333	141	52
1981	46	61	63	52	60	48	51	92	46	66	68	76
1982	77	53	56	56	43	40	35	72	68	84	273	237
1983	109	58	52	52	46	137	373	1774	2076	706	533	78
1984	75	99	113	97	135	148	291	1112	689	301	679	231
1985	415	242	134	106	94	106	159	1182	472	303	242	62

Table A2.14. Monthly 7-day low flows for each year of record at Englewood.

Water year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1955	24	45	38	37	38	34	34	110	62	40	261	130
1956	38	59	50	37	37	43	42	215	153	65	39	15
1957	18	41	37	33	37	41	62	270	1190	753	535	73
1958	86	158	95	74	78	71	217	585	307	123	53	44
1959	58	53	51	46	60	61	121	263	232	131	82	33
1960	82	75	65	61	71	94	483	485	245	222	43	36
1961	50	75	83	77	74	102	132	324	130	196	432	274
1962	278	338	150	119	180	155	286	229	282	195	72	35
1963	32	44	60	52	55	50	35	39	34	26	34	107
1964	46	61	68	50	50	58	105	196	118	145	72	40
1965	36	60	51	43	44	60	87	284	402	520	670	335
1966	190	117	80	76	85	66	99	109	85	72	84	49
1967	56	81	68	75	53	47	50	86	135	125	206	96
1968	72	96	86	81	83	83	97	198	154	165	213	108
1969	105	79	70	46	50	68	73	158	722	488	341	103
1970	137	308	219	169	119	126	314	2129	1461	597	220	143
1971	142	129	109	95	120	113	114	427	368	309	230	78
1972	66	75	78	84	82	70	68	117	239	153	139	65
1973	65	78	75	79	93	111	164	1143	981	461	268	64
1974	120	117	97	109	123	222	322	280	153	165	80	53
1975	88	75	75	76	78	79	82	186	352	531	236	119
1976	44	48	64	78	74	74	78	121	100	247	220	113
1977	89	87	88	78	60	64	102	153	60	72	122	58
1978	50	55	58	58	60	56	47	78	53	121	104	48
1979	55	49	41	46	61	63	151	253	493	226	105	51
1980	54	67	84	85	112	100	175	2155	1203	407	166	53
1981	48	71	64	54	62	64	59	115	48	69	74	89
1982	77	54	57	56	46	43	37	79	94	138	305	248
1983	141	59	59	53	48	136	405	1887	2259	845	556	92
1984	76	93	115	107	140	154	292	1393	758	312	664	265
1985	529	281	208	112	98	110	182	1214	572	393	277	64

Table A2.15. Monthly 1-day low flows for each year of record at Henderson.

Water year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1955	13	22	17	31	18	46	25	112	181	52	189	166
1956	26	52	37	27	35	41	12	140	316	84	60	69
1957	20	9	42	36	114	73	32	24	1210	749	405	126
1958	129	159	86	87	84	90	211	371	278	174	67	54
1959	54	64	52	56	56	63	78	93	522	136	74	56
1960	62	67	54	24	104	152	234	269	454	185	72	61
1961	60	65	66	65	60	69	47	120	365	205	148	132
1962	403	497	311	240	300	177	392	98	148	235	100	53
1963	14	9	66	58	68	64	28	93	80	98	104	108
1964	40	20	51	62	134	81	22	145	141	202	83	65
1965	42	90	71	69	135	82	13	165	108	428	251	230
1966	196	96	80	135	85	87	60	120	125	73	102	90
1967	132	179	169	171	145	116	104	114	242	158	240	116
1968	122	86	102	104	98	122	124	138	233	236	294	208
1969	77	104	102	83	86	74	60	129	835	359	322	199
1970	200	510	366	310	214	210	613	1480	1440	426	246	143
1971	322	300	360	420	280	260	172	338	332	372	322	206
1972	285	265	224	232	185	103	97	185	316	270	189	189
1973	193	161	168	168	228	214	214	1720	1100	372	290	265
1974	426	300	265	270	322	426	485	242	360	322	206	139
1975	255	161	147	137	131	124	160	80	219	414	157	159
1976	204	176	156	164	156	145	85	137	102	365	227	231
1977	148	162	148	140	124	108	27	182	145	130	182	127
1978	88	122	159	140	148	51	52	127	208	266	221	167
1979	130	200	179	155	176	191	197	269	599	286	266	229
1980	188	226	226	250	301	297	324	2180	944	415	320	200
1981	150	164	176	167	120	105	135	197	226	229	242	185
1982	188	179	176	155	161	64	81	107	210	407	420	259
1983	259	269	367	415	232	246	622	2120	2700	932	1000	310
1984	200	300	340	492	545	520	500	1170	1240	420	776	450
1985	840	718	312	260	280	252	229	1250	363	403	375	272

Table A2.16. Monthly 4-day low flows for each year of record at Henderson.

Water year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1955	13	36	22	35	32	48	39	88	115	61	120	127
1956	40	53	42	34	42	41	12	88	257	98	70	74
1957	27	10	40	38	90	74	36	70	703	371	298	107
1958	106	107	89	85	75	76	132	156	298	143	72	59
1959	57	66	53	58	61	66	75	139	201	172	78	58
1960	63	67	57	34	83	122	162	121	261	172	78	66
1961	69	67	67	66	62	80	73	170	383	163	116	156
1962	209	223	198	133	179	148	169	181	116	233	93	58
1963	12	14	68	59	71	67	36	77	87	82	80	88
1964	37	21	61	63	104	80	34	105	127	152	82	69
1965	52	93	70	69	119	91	22	157	80	238	342	155
1966	201	102	82	93	86	86	75	93	99	72	105	98
1967	97	102	99	100	100	107	91	100	137	93	144	121
1968	87	84	79	81	78	87	108	120	124	141	168	143
1969	81	80	80	76	78	73	62	88	262	199	190	129
1970	141	274	173	181	131	109	229	671	611	270	193	160
1971	145	142	148	158	178	123	120	250	168	146	170	183
1972	135	132	122	113	121	93	89	100	200	210	184	123
1973	113	151	103	101	111	188	142	483	686	318	186	196
1974	170	179	162	126	136	285	256	191	193	200	135	157
1975	117	168	104	93	96	116	177	104	108	383	165	143
1976	112	107	99	94	118	116	75	101	119	151	171	123
1977	126	102	98	92	89	133	60	107	143	88	116	94
1978	95	84	93	98	94	55	57	103	147	224	146	112
1979	93	107	104	103	98	108	119	171	215	212	166	122
1980	126	128	130	121	137	147	199	1136	798	346	202	139
1981	104	96	107	98	99	80	107	162	236	122	130	114
1982	101	107	100	100	94	67	84	114	121	213	200	157
1983	118	153	153	174	142	115	272	821	1106	966	363	207
1984	128	133	141	213	219	196	188	818	613	358	483	518
1985	306	523	222	127	188	190	127	638	396	178	231	159

Table A2.17. Monthly 7-day low flows for each year of record at Henderson.

Water year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1955	13	33	22	36	32	46	44	128	211	68	240	169
1956	47	54	44	37	42	44	13	152	389	106	80	76
1957	35	10	44	38	125	96	53	72	1349	882	491	137
1958	160	168	94	86	87	93	300	455	324	189	73	60
1959	61	68	53	56	59	67	87	200	581	206	81	60
1960	65	68	58	42	101	177	343	454	513	268	80	67
1961	74	68	68	68	62	90	114	239	452	299	385	168
1962	444	552	345	291	348	319	448	225	216	264	109	61
1963	14	12	69	61	73	68	44	101	108	101	109	119
1964	41	23	59	64	138	88	41	149	202	228	93	72
1965	56	128	75	73	153	96	35	203	313	530	382	309
1966	222	107	83	139	114	90	101	188	164	110	121	118
1967	144	187	179	180	181	139	138	180	307	286	252	165
1968	151	90	103	111	112	139	167	192	260	308	314	215
1969	82	103	102	84	89	74	65	135	986	504	414	214
1970	353	562	431	324	221	221	622	1731	1726	556	383	250
1971	340	342	377	458	299	286	207	460	433	454	344	252
1972	292	271	249	245	187	130	133	231	441	331	304	219
1973	226	183	183	179	241	255	300	1693	1150	536	482	312
1974	444	329	284	320	333	559	628	416	474	425	226	222
1975	273	179	155	154	151	147	191	303	298	631	297	198
1976	222	198	166	172	199	180	113	185	244	426	404	312
1977	286	175	153	152	143	146	96	257	145	141	216	141
1978	100	152	164	141	154	77	73	195	299	313	253	174
1979	160	212	194	171	180	199	236	348	757	428	284	245
1980	220	238	237	279	323	312	380	3010	1156	570	393	210
1981	158	169	180	174	130	140	159	223	240	254	258	203
1982	195	184	187	170	168	69	105	182	235	493	481	273
1983	267	339	393	423	248	251	829	2421	3539	1287	1007	379
1984	229	324	350	513	560	545	573	1833	1354	633	846	587
1985	1282	757	322	287	332	310	349	1310	642	499	408	305

Table A2.18. Monthly 1-day low flows for each year of record at Boulder.

Water year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1960	26	74	37	22	38	102	68	196	98	47	133	26
1961	31	16	53	20	19	42	107	163	111	68	35	43
1962	51	86	67	65	75	48	97	41	48	173	74	19
1963	15	17	34	13	19	52	21	100	49	64	36	26
1964	6	9	31	13	18	30	41	48	51	82	41	25
1965	12	20	30	19	14	20	33	40	78	100	47	23
1966	26	23	27	24	19	53	18	13	41	86	45	17
1967	18	9	14	5	9	8	4	18	119	61	95	24
1968	31	37	21	22	54	57	55	39	103	76	34	28
1969	15	26	13	13	35	14	29	425	248	72	50	19
1970	37	98	66	54	50	60	138	175	77	50	43	24

Table A2.19. Monthly 4-day low flows for each year of record at Boulder.

Water year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1960	30	73	34	23	37	96	79	180	90	53	125	29
1961	32	17	54	40	38	52	111	177	122	90	39	49
1962	62	92	75	69	68	56	101	44	59	159	84	23
1963	16	17	26	14	19	58	26	103	58	70	39	36
1964	7	9	36	14	18	37	52	52	76	98	43	27
1965	12	20	32	21	21	25	45	47	112	129	50	28
1966	28	30	31	25	24	59	18	28	48	95	47	25
1967	21	15	15	6	11	11	8	20	126	91	104	31
1968	34	38	28	27	57	61	58	43	122	102	36	29
1969	19	27	16	18	38	14	33	350	288	76	48	22
1970	37	94	66	57	54	63	122	199	88	56	45	26

Table A2.20. Monthly 7-day low flows for each year of record at Boulder.

Water year		Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1960	39	68	35	24	36	92	85	178	117	60	134	29
1961	32	18	56	44	44	57	112	173	122	102	46	51
1962	65	90	75	70	69	57	99	50	57	159	106	32
1963	28	29	31	15	22	60	30	107	66	73	40	36
1964	9	10	36	14	19	37	55	61	77	100	47	27
1965	14	20	31	21	21	27	55	53	112	143	53	31
1966	30	35	37	27	24	59	25	29	50	103	47	29
1967	24	15	16	8	11	11	9	19	128	109	112	36
1968	36	39	29	29	58	62	59	58	134	119	38	31
1969	22	27	16	19	38	15	34	295	387	86	46	26
1970	38	96	67	59	54	65	112	201	108	61	47	30

Table A2.21. Monthly 1-day low flows for each year of record at Lyons.

Water year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1955	1	1	5	4	4	5	8	32	185	134	55	13
1956	2	1	7	4	5	6	6	64	249	95	65	9
1957	1	1	4	4	3	0	1	249	516	305	127	31
1958	17	6	6	6	3	3	12	119	264	78	51	14
1959	1	5	5	1	1	8	8	112	347	128	47	22
1960	40	10	6	3	7	10	28	47	313	128	32	20
1961	9	1	6	3	3	12	43	92	420	118	84	62
1962	69	27	8	11	12	11	23	120	150	148	39	20
1963	7	4	3	3	5	5	5	24	177	54	50	17
1964	4	9	4	4	5	1	14	19	170	100	24	18
1965	4	4	3	4	6	1	5	96	186	287	86	39
1966	11	5	6	4	7	5	7	36	161	79	18	7
1967	12	4	3	2	3	4	7	12	262	145	70	12
1968	13	12	13	11	8	12	24	72	312	132	59	16
1969	7	5	7	6	7	6	4	30	472	120	70	37
1970	37	42	9	5	6	9	15	85	355	145	73	47
1971	44	20	9	6	7	10	4	168	390	174	110	62
1972	30	16	9	8	9	9	14	42	301	132	75	36
1973	20	12	11	11	8	11	12	105	258	177	124	26
1974	10	7	4	4	16	15	12	58	165	145	58	30
1975	17	18	14	11	5	5	20	88	288	237	108	40
1976	12	12	9	8	5	8	8	27	198	124	64	31
1977	11	5	6	4	3	3	8	55	110	75	67	16
1978	14	7	4	6	7	5	14	88	198	206	107	21
1979	10	12	9	10	10	9	35	131	541	207	85	42
1980	18	16	16	21	23	26	28	490	448	133	103	37
1981	24	19	8	7	8	10	14	56	129	84	45	18
1982	15	11	9	8	3	3	5	47	240	267	156	74
1983	32	20	13	15	13	14	55	169	589	264	109	42
1984	28	18	14	16	14	18	36	171	288	271	194	97
1985	63	26	16	14	15	16	22	162	187	148	68	30

Table A2.22. Monthly 4-day low flows for each year of record at Lyons.

Water year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1955	1	1	6	5	5	6	9	40	193	137	61	16
1956	2	1	8	5	6	7	8	76	257	97	70	11
1957	1	5	5	4	4	0	3	316	570	330	155	33
1958	19	10	9	6	3	3	14	174	282	81	57	15
1959	1	5	6	1	1	11	14	124	357	132	50	23
1960	43	15	7	3	8	13	30	54	323	136	34	20
1961	12	1	7	3	3	13	51	103	424	127	91	66
1962	70	33	13	13	14	12	28	124	206	164	43	21
1963	7	6	5	5	6	6	7	34	199	68	79	22
1964	5	13	6	5	5	1	17	26	197	113	29	19
1965	4	6	4	5	7	2	7	109	212	365	92	41
1966	12	7	8	4	8	6	7	40	165	89	21	7
1967	14	8	3	2	4	5	9	13	309	163	72	19
1968	21	17	13	12	8	13	29	91	371	136	66	21
1969	9	6	9	8	8	6	5	58	596	141	73	37
1970	46	45	18	5	6	10	29	93	369	155	74	47
1971	47	21	9	7	7	10	6	183	432	203	111	68
1972	33	17	9	9	10	9	15	43	311	139	78	38
1973	21	17	13	13	9	12	14	118	320	202	124	27
1974	14	8	5	5	17	16	15	63	174	168	62	31
1975	21	21	15	11	6	6	22	89	412	249	110	42
1976	13	14	10	9	7	10	10	29	207	132	67	34
1977	13	8	8	5	4	4	11	64	115	77	71	18
1978	15	11	8	8	8	8	17	91	262	223	119	31
1979	11	13	12	11	12	11	37	148	557	232	91	45
1980	19	20	18	22	25	28	32	531	460	152	106	38
1981	26	20	12	8	11	13	18	58	130	88	48	21
1982	17	13	10	10	7	5	13	63	253	280	169	75
1983	37	23	17	17	15	17	57	175	651	294	113	46
1984	30	23	16	18	17	19	36	183	301	294	201	107
1985	71	31	18	16	19	18	29	169	220	157	74	35

Table A2.23. Monthly 7-day low flows for each year of record at Lyons.

Water year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1955	2	1	6	6	5	6	9	43	202	143	72	19
1956	2	4	8	7	6	7	11	94	269	101	78	11
1957	1	7	5	5	4	0	25	346	625	355	154	34
1958	22	13	9	6	6	3	14	219	317	86	60	16
1959	1	6	6	1	4	11	18	133	419	137	54	24
1960	43	19	8	3	9	13	35	155	335	140	41	21
1961	13	2	7	3	3	14	59	110	452	132	92	72
1962	72	36	15	14	16	13	31	134	246	177	47	21
1963	9	7	7	6	6	6	9	59	233	77	115	31
1964	6	14	8	6	5	1	17	29	219	122	33	20
1965	5	7	4	5	7	2	11	109	222	425	103	46
1966	13	7	10	5	8	6	8	60	172	92	27	9
1967	15	10	4	3	5	6	10	14	328	203	74	23
1968	24	20	13	13	8	14	31	105	413	141	74	26
1969	11	7	10	9	8	7	6	263	731	180	78	41
1970	46	46	23	6	6	10	60	130	386	172	76	52
1971	49	23	9	7	7	11	11	214	453	220	114	75
1972	34	17	10	10	11	10	16	47	330	142	86	39
1973	22	17	14	13	9	13	16	298	340	220	124	29
1974	17	9	7	6	20	18	17	65	194	183	63	33
1975	22	22	16	12	6	8	26	90	411	278	113	43
1976	16	15	11	9	8	11	12	36	223	143	84	38
1977	14	9	8	5	5	6	11	64	128	78	76	20
1978	16	12	10	9	8	9	20	100	337	229	124	33
1979	13	14	12	11	12	12	43	173	590	247	112	46
1980	20	20	19	23	26	29	43	593	500	177	110	39
1981	26	21	13	8	11	13	18	58	135	92	56	25
1982	17	14	11	11	8	7	15	90	261	292	177	75
1983	38	25	18	17	15	24	60	178	670	304	124	47
1984	35	23	16	18	17	19	37	196	323	313	218	107
1985	75	37	19	16	19	18	30	175	262	163	76	35

Table A2.24. Monthly 1-day low flows for each year of record at Longmont based on a regression of daily flows.

Water year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1955	8	9	9	11	13	13	12	19	115	78	39	22
1956	14	14	11	10	7	11	14	41	154	68	50	17
1957	10	17	16	8	13	10	10	208	504	307	130	55
1958	52	46	34	35	16	40	43	156	192	97	58	32
1959	29	27	24	20	16	27	46	110	293	120	80	41
1960	60	47	32	7	24	31	46	54	217	116	46	37
1961	31	32	30	15	26	38	53	76	260	112	70	76
1962	119	93	65	43	26	42	55	88	161	183	62	50
1963	33	29	27	17	21	28	10	17	130	48	45	41
1964	30	32	28	24	20	21	25	18	149	89	43	28
1965	22	22	19	18	19	22	28	60	131	268	118	83
1966	55	38	39	23	26	23	16	30	105	62	49	29
1967	31	21	19	21	19	13	11	21	227	110	97	57
1968	40	39	31	31	51	34	32	67	218	125	71	59
1969	45	28	18	24	21	23	15	25	335	103	68	49
1970	48	116	78	54	50	40	73	162	277	140	102	60
1971	78	81	56	28	33	35	26	299	316	177	103	84
1972	67	49	46	31	41	26	27	58	196	117	80	54
1973	43	45	24	49	46	37	34	196	255	175	112	72
1974	51	48	24	43	49	54	35	81	160	133	84	62
1975	58	51	43	43	35	31	38	75	239	196	113	72
1976	46	53	42	28	15	22	17	42	140	107	83	66
1977	43	39	33	28	31	28	33	24	44	74	53	47
1978	37	31	27	23	26	24	22	64	171	66	58	42
1979	38	28	25	30	39	33	39	63	200	94	73	56
1980	61	64	66	61	68	79	107	640	162	123	120	68
1981	57	48	38	36	28	30	31	30	44	66	92	47
1982	42	37	27	27	27	23	22	26	44	61	150	72
1983	81	61	28	55	54	55	144	272	863	342	144	70
1984	60	38	40	36	66	61	83	259	286	237	189	118
1985	90	94	66	55	52	48	45	78	82	114	88	57

Table A2.25. Monthly 4-day low flows for each year of record at Longmont based on a regression of daily flows.

Water year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1955	9	9	12	12	14	15	12	23	52	58	42	24
1956	14	17	13	8	10	14	14	34	115	68	48	15
1957	12	19	16	11	14	11	19	95	258	281	86	44
1958	45	46	36	34	33	34	36	71	174	63	46	33
1959	30	28	25	21	28	29	35	79	100	77	59	44
1960	50	47	29	7	25	33	35	37	110	80	45	34
1961	31	33	33	25	31	34	44	45	264	76	64	54
1962	76	56	48	42	39	41	40	45	76	107	58	38
1963	34	30	28	19	22	29	12	23	78	50	43	35
1964	31	33	29	25	21	21	27	22	64	69	45	28
1965	24	23	19	18	21	23	29	57	60	148	108	48
1966	51	36	39	31	31	23	18	31	62	51	45	30
1967	31	24	20	22	20	14	13	27	80	113	52	58
1968	39	33	32	31	38	35	34	43	87	68	56	47
1969	39	29	23	27	22	23	17	33	114	110	50	47
1970	37	58	49	50	37	37	49	64	98	124	54	44
1971	49	49	42	30	34	32	29	197	119	88	55	51
1972	47	42	36	31	37	29	29	38	92	74	59	49
1973	36	43	35	39	35	34	33	81	119	95	66	52
1974	42	38	36	36	39	37	37	43	93	80	57	52
1975	39	41	37	38	32	33	35	47	129	110	73	49
1976	41	37	38	30	28	22	20	34	66	74	84	41
1977	36	36	32	29	31	30	33	28	34	48	37	36
1978	38	31	27	24	27	25	26	39	88	47	68	39
1979	33	31	28	30	34	33	37	69	161	51	45	57
1980	38	43	47	38	44	55	50	393	146	87	68	58
1981	43	37	35	33	32	33	31	32	39	44	61	44
1982	34	35	29	29	27	24	24	29	42	62	70	67
1983	47	43	38	37	37	37	65	103	259	245	88	57
1984	39	36	41	35	43	40	45	98	154	133	90	69
1985	46	64	44	40	38	38	34	58	56	52	50	45

Table A2.26. Monthly 7-day low flows for each year of record at Longmont based on a regression of daily flows.

Water year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1955	10	10	13	12	14	15	13	21	110	85	49	25
1956	15	17	15	10	9	14	16	47	167	75	52	17
1957	12	20	16	12	15	12	16	225	595	314	127	62
1958	61	55	39	39	42	39	48	161	201	105	63	34
1959	31	29	25	23	27	30	49	126	287	133	87	46
1960	62	61	32	8	26	32	50	66	222	123	49	38
1961	32	35	35	30	33	40	61	73	271	128	79	85
1962	136	102	72	46	49	52	58	100	192	207	64	49
1963	35	31	30	21	24	27	13	22	146	58	64	40
1964	31	34	31	26	22	21	29	24	166	101	46	29
1965	24	24	20	19	22	23	28	71	142	303	117	88
1966	55	48	46	33	33	24	19	30	111	75	59	31
1967	32	26	21	22	20	14	14	25	229	117	104	65
1968	43	43	33	35	53	37	37	67	214	131	81	66
1969	48	30	24	25	22	24	18	35	543	113	71	51
1970	57	116	79	58	51	42	82	192	300	144	98	68
1971	82	82	54	36	40	39	34	317	360	181	109	102
1972	71	52	45	41	47	30	29	60	199	127	91	54
1973	45	51	47	57	49	37	38	197	289	177	117	76
1974	55	50	41	47	61	57	40	90	194	147	89	67
1975	60	54	48	43	40	35	42	81	323	217	113	76
1976	49	56	42	39	33	23	21	48	146	123	84	74
1977	46	43	33	30	31	30	34	30	50	85	57	51
1978	40	33	27	24	27	26	25	73	215	99	79	51
1979	43	31	29	30	40	35	46	119	223	103	85	62
1980	63	73	72	70	72	91	116	663	206	132	132	74
1981	62	51	41	38	33	34	31	34	49	82	93	48
1982	46	38	30	30	27	25	25	32	55	71	159	76
1983	83	62	48	56	57	66	158	301	898	346	144	69
1984	58	49	44	40	68	68	89	279	307	268	206	112
1985	113	94	68	58	56	51	50	124	100	129	100	61

Table A2.27. Monthly 1-day low flows for each year of record at Longmont based on a regression of log-transformed daily flows.

Water year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1955	10	10	13	15	15	16	11	12	23	28	26	24
1956	14	12	15	13	11	15	17	23	62	42	33	20
1957	11	14	18	12	16	8	10	145	375	205	107	55
1958	51	42	32	33	34	31	43	140	107	76	51	34
1959	19	26	26	16	17	28	46	70	159	94	73	43
1960	58	48	32	10	25	32	38	50	110	89	46	39
1961	33	20	30	16	27	38	47	56	98	75	50	66
1962	113	90	61	43	43	44	54	49	93	123	61	51
1963	32	28	26	19	22	27	13	16	73	41	39	42
1964	28	33	26	24	22	15	26	19	78	67	37	30
1965	23	22	20	20	22	19	27	28	73	143	99	81
1966	51	36	36	24	30	26	19	25	45	46	45	29
1967	33	22	19	19	19	15	15	23	104	69	76	57
1968	41	39	33	33	45	36	33	47	96	79	63	57
1969	42	27	21	25	23	24	17	22	181	77	54	48
1970	47	111	65	45	43	39	67	117	151	112	94	56
1971	74	76	50	28	33	36	27	265	194	121	78	78
1972	67	49	43	31	40	29	30	57	81	77	64	53
1973	44	45	27	48	42	38	36	184	120	109	84	71
1974	49	43	26	39	58	53	36	66	112	103	79	62
1975	58	52	44	43	34	30	39	47	115	117	96	71
1976	45	51	42	30	17	24	20	39	72	71	77	65
1977	43	39	33	28	31	28	33	24	44	74	53	47
1978	37	31	27	23	26	24	22	64	171	66	58	42
1979	38	28	25	30	39	33	39	63	200	94	73	56
1980	61	64	66	61	68	79	107	640	162	123	120	68
1981	57	48	38	36	28	30	31	30	44	66	92	47
1982	42	37	27	27	27	23	22	26	44	61	150	72
1983	79	61	30	53	52	54	137	247	768	300	130	68
1984	60	39	41	38	62	59	81	236	211	171	148	108
1985	90	94	66	55	52	48	45	78	82	114	88	57

Table A2.28. Monthly 4-day low flows for each year of record at Longmont based on a regression of log-transformed daily flows.

Water year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1955	11	10	15	15	16	18	11	12	28	31	27	25
1956	14	15	16	13	11	17	18	24	64	45	38	20
1957	11	19	18	15	17	9	13	162	425	201	102	58
1958	54	46	36	36	34	32	45	143	108	81	52	36
1959	20	27	27	17	17	31	48	80	177	100	76	45
1960	59	55	30	11	26	34	47	57	116	90	46	40
1961	33	24	32	23	28	41	48	56	111	82	57	73
1962	124	96	65	44	47	54	55	50	104	145	63	50
1963	34	30	27	21	24	28	15	17	75	43	47	39
1964	28	34	28	25	22	16	27	21	80	68	38	30
1965	24	24	20	21	24	21	28	30	76	147	103	83
1966	51	39	40	30	32	26	21	27	51	51	48	31
1967	33	25	20	20	20	16	16	25	108	71	80	59
1968	43	41	34	35	46	37	34	50	99	81	69	62
1969	44	29	25	27	24	25	19	23	221	82	56	49
1970	49	112	63	48	45	40	78	125	158	112	88	61
1971	76	74	50	30	38	38	30	272	182	132	80	84
1972	69	51	43	36	43	31	30	58	85	84	68	52
1973	45	50	41	53	44	38	38	198	127	114	87	72
1974	51	44	38	40	60	54	38	74	122	107	81	63
1975	59	52	46	43	37	32	40	51	126	127	92	73
1976	46	54	43	35	29	25	23	43	77	76	78	68
1977	46	43	32	29	32	30	34	28	48	78	54	49
1978	39	32	27	24	27	25	25	74	211	90	68	48
1979	40	30	28	30	40	34	42	124	210	98	81	60
1980	62	70	71	66	70	83	118	632	182	127	126	70
1981	60	50	40	37	32	32	31	32	48	79	86	46
1982	44	37	28	28	27	24	24	30	52	62	154	74
1983	80	62	43	55	54	55	144	264	808	281	130	67
1984	59	42	44	40	64	63	84	243	226	177	155	110
1985	104	94	64	56	54	48	49	96	94	127	93	59

Table A2.29. Monthly 7-day low flows for each year of record at Longmont based on a regression of log-transformed daily flows.

Water year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1955	11	11	16	16	17	18	12	12	34	32	30	26
1956	15	17	18	13	12	17	18	24	70	48	40	20
1957	11	21	18	15	17	9	14	167	437	208	103	61
1958	60	52	37	36	35	32	48	138	125	83	54	36
1959	20	29	27	17	18	32	48	93	169	106	80	47
1960	60	61	31	11	27	33	49	59	122	92	49	40
1961	34	24	34	26	29	42	51	55	124	87	61	77
1962	129	97	66	46	53	55	57	51	144	157	62	50
1963	34	30	29	22	25	27	15	17	79	47	52	41
1964	30	34	31	26	22	16	26	22	86	70	38	30
1965	25	26	20	21	24	21	27	33	79	158	109	85
1966	51	44	44	32	33	26	22	27	54	55	50	32
1967	33	28	21	21	21	17	17	28	115	77	79	64
1968	44	44	35	37	46	38	35	52	105	83	71	64
1969	44	30	27	27	24	25	21	25	284	84	57	50
1970	55	110	67	49	45	41	78	134	167	114	90	64
1971	79	76	48	34	39	39	33	278	197	132	83	91
1972	70	52	43	40	44	32	31	58	89	89	72	53
1973	46	51	47	53	45	39	39	183	139	127	88	74
1974	54	45	40	40	61	55	42	79	133	115	84	67
1975	59	54	48	42	40	34	43	57	150	138	95	74
1976	48	55	41	38	33	26	24	44	78	81	79	72
1977	46	43	33	30	31	30	34	30	50	85	57	51
1978	40	33	27	24	27	26	25	73	215	99	79	51
1979	43	31	29	30	40	35	46	119	123	103	85	62
1980	63	73	72	70	72	91	116	663	206	132	132	74
1981	62	51	41	38	33	34	31	34	49	82	93	48
1982	46	38	30	30	27	25	25	32	55	71	159	76
1983	81	62	48	55	56	56	149	275	790	304	130	67
1984	58	50	45	42	65	64	86	251	235	187	159	112
1985	113	94	68	58	56	51	50	124	100	129	100	61

Table A2.30. Monthly 1-day low flows for each year of record at Longmont based on a regression of monthly low flows.

Water year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1955	14	13	14	17	18	19	10	13	23	29	26	24
1956	18	13	18	15	13	18	15	20	59	43	34	24
1957	11	17	22	15	18	10	13	130	288	164	101	57
1958	55	45	37	38	35	37	46	125	91	67	50	38
1959	25	31	28	17	23	32	41	64	128	76	65	46
1960	60	46	35	11	30	37	33	51	99	84	48	39
1961	34	24	34	21	32	42	46	56	89	68	50	63
1962	108	85	57	44	42	43	44	41	67	96	61	51
1963	37	31	28	21	26	32	14	19	64	43	41	40
1964	27	36	31	28	25	19	23	21	67	58	33	33
1965	24	25	23	23	24	22	19	29	67	118	85	78
1966	55	38	38	27	34	26	22	27	45	47	37	34
1967	36	26	23	22	23	19	18	23	89	65	64	49
1968	41	41	36	35	51	37	34	46	78	72	62	56
1969	45	30	24	28	27	27	18	22	147	71	53	50
1970	49	99	66	48	47	42	70	81	123	104	80	56
1971	71	76	54	32	36	39	27	209	158	104	74	74
1972	67	52	47	36	43	30	33	44	75	72	61	55
1973	46	45	30	49	46	40	38	163	96	83	78	70
1974	51	48	26	40	54	55	40	50	93	92	78	64
1975	56	53	47	45	33	29	40	46	94	92	88	68
1976	46	53	43	32	21	27	21	31	64	62	70	63
1977	43	35	35	27	31	22	29	31	45	42	56	32
1978	34	32	30	29	32	27	29	73	149	104	68	44
1979	39	47	27	32	36	38	44	53	206	107	81	69
1980	55	42	64	63	76	91	99	378	157	99	91	68
1981	51	51	43	38	31	35	29	38	36	59	61	34
1982	31	35	37	35	24	21	17	23	57	100	111	89
1983	73	61	31	56	55	55	130	210	580	231	120	67
1984	57	41	41	42	63	63	81	203	178	150	126	100
1985	94	75	60	49	48	51	50	103	98	113	72	63

Table A2.31. Monthly 4-day low flows for each year of record at Longmont based on a regression of monthly low flows.

Water year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1955	15	15	18	19	20	21	13	17	29	30	28	25
1956	19	17	20	17	16	19	19	23	48	38	34	23
1957	13	22	22	18	19	13	20	86	151	94	66	44
1958	43	38	33	32	31	30	37	81	67	51	41	32
1959	22	27	26	17	22	30	36	54	86	57	50	38
1960	45	39	30	15	27	33	34	44	69	58	39	34
1961	30	24	30	25	28	34	39	44	67	51	44	51
1962	71	59	45	36	37	40	41	37	57	71	47	40
1963	31	29	27	23	25	28	17	21	52	38	41	34
1964	25	32	28	26	24	19	24	24	51	46	31	30
1965	23	25	23	22	25	21	22	30	53	78	59	53
1966	41	34	34	28	30	24	22	27	41	41	34	30
1967	31	27	23	22	22	20	20	25	64	51	49	41
1968	37	36	32	31	38	32	32	40	60	53	48	43
1969	37	28	26	27	25	26	19	26	100	55	43	40
1970	41	64	51	37	36	35	55	59	81	67	55	46
1971	51	51	40	29	31	33	26	109	89	70	54	54
1972	49	40	36	33	36	27	30	38	57	55	48	42
1973	37	39	36	42	37	33	34	96	69	61	56	50
1974	41	37	30	34	42	42	34	43	66	64	54	47
1975	43	42	38	36	31	28	34	40	71	66	59	50
1976	37	41	36	31	29	26	22	32	52	50	52	48
1977	35	32	32	28	27	24	29	31	39	36	45	29
1978	30	30	30	29	29	27	27	57	99	70	53	39
1979	33	37	29	30	31	33	39	71	113	71	57	49
1980	42	44	46	48	53	59	64	164	101	67	61	48
1981	41	41	38	32	32	32	29	35	34	48	45	30
1982	29	31	32	33	28	23	22	26	48	69	73	59
1983	52	45	36	42	42	43	77	112	226	120	74	48
1984	44	36	34	35	46	46	55	107	103	89	80	66
1985	65	52	44	39	39	40	42	73	69	72	54	48

Table A2.32. Monthly 7-day low flows for each year of record at Longmont based on a regression of monthly low flows.

Water year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1955	12	12	17	17	18	20	10	15	38	35	32	27
1956	17	19	20	15	13	17	18	24	71	50	42	23
1957	10	24	20	16	17	10	31	170	376	189	105	59
1958	60	53	39	37	39	33	47	147	122	74	54	38
1959	22	30	27	15	28	33	48	89	162	94	75	48
1960	60	55	35	12	29	37	47	75	119	91	52	40
1961	34	24	35	28	29	42	50	60	123	82	61	76
1962	122	94	63	46	53	51	54	47	128	126	65	49
1963	36	32	30	24	26	28	14	22	76	50	59	47
1964	27	37	33	27	24	17	24	24	78	62	36	32
1965	24	27	22	22	25	20	24	35	81	148	96	81
1966	53	41	44	31	34	24	21	31	56	55	41	33
1967	36	30	23	22	22	18	19	25	111	83	68	56
1968	45	44	36	37	47	36	37	53	101	79	70	61
1969	47	30	28	28	26	26	18	41	258	87	58	52
1970	57	105	77	46	43	41	94	103	156	114	84	65
1971	76	76	50	35	36	38	31	242	178	122	80	83
1972	69	52	44	41	46	30	33	50	88	86	70	55
1973	45	50	48	54	45	39	41	213	124	105	84	70
1974	54	46	37	42	58	56	42	59	107	102	80	65
1975	58	55	48	44	36	34	44	56	139	116	94	73
1976	48	53	42	39	33	27	24	37	79	74	79	69
1977	43	38	36	29	29	26	32	34	50	43	63	34
1978	33	34	34	35	31	28	30	78	209	120	83	50
1979	41	46	35	35	36	39	53	121	256	120	93	69
1980	55	61	64	67	78	93	111	440	231	119	99	68
1981	52	53	48	37	38	36	31	53	42	70	63	37
1982	34	34	36	38	32	23	22	31	73	115	127	91
1983	75	61	49	55	53	61	139	241	661	280	128	68
1984	61	51	42	42	63	63	83	225	215	174	148	108
1985	109	78	59	50	50	50	54	134	122	125	85	67

Table A2.33. Monthly 1-day low flows for each year of record at Platteville

Water year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1955	38	39	29	38	43	44	16	16	22	34	37	48
1956	56	45	36	32	25	39	30	24	80	64	51	52
1957	35	55	56	34	46	43	45	248	646	331	206	132
1958	146	144	110	113	122	133	124	285	147	131	94	90
1959	104	89	77	64	96	82	118	111	222	137	141	106
1960	131	130	100	25	75	95	62	100	157	158	103	87
1961	87	103	95	57	103	109	88	95	124	120	84	126
1962	268	242	190	120	110	114	98	57	110	183	137	127
1963	107	95	89	56	69	91	28	28	98	75	72	91
1964	75	94	94	81	68	74	45	36	106	98	64	69
1965	66	69	64	59	60	75	44	37	104	209	179	194
1966	164	118	115	77	93	68	50	42	60	77	82	91
1967	87	74	67	72	67	47	36	46	141	105	124	138
1968	105	107	87	85	161	91	68	76	112	126	126	154
1969	141	87	56	74	65	70	44	34	250	126	96	105
1970	102	271	229	172	159	121	217	167	209	209	170	116
1971	164	226	172	90	102	102	76	548	292	198	136	159
1972	167	138	138	96	124	74	74	83	107	124	116	119
1973	107	121	70	141	141	105	96	434	159	143	143	184
1974	150	152	75	135	147	152	100	93	172	175	175	158
1975	149	139	124	123	102	81	89	72	150	152	176	159
1976	126	152	125	81	52	63	44	56	95	103	145	151
1977	114	104	104	76	98	63	73	46	66	66	105	68
1978	78	83	91	77	86	71	61	143	323	190	122	102
1979	102	130	61	80	90	103	87	80	394	196	167	161
1980	144	102	188	168	217	273	303	973	278	198	189	161
1981	121	129	125	109	80	89	61	62	47	105	130	72
1982	66	85	97	92	75	60	38	32	76	168	224	199
1983	185	163	70	155	157	153	371	554	1720	561	275	155
1984	136	93	100	100	189	175	212	526	377	298	254	219
1985	226	204	169	130	125	132	118	200	177	232	151	155

Table A2.34. Monthly 4-day low flows for each year of record at Platteville

Water year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1955	40	41	37	39	46	50	16	17	30	38	41	53
1956	56	51	42	30	27	39	34	26	83	70	60	51
1957	40	62	57	40	50	48	55	280	778	328	198	137
1958	154	147	116	122	137	138	130	295	166	141	98	92
1959	107	92	80	66	96	87	123	136	268	153	160	113
1960	133	136	98	28	78	99	82	116	171	159	103	90
1961	88	103	102	87	107	111	90	96	146	123	99	149
1962	300	264	197	123	126	154	122	60	128	227	148	128
1963	107	97	90	62	74	91	28	28	109	80	86	93
1964	79	95	95	85	70	75	45	38	106	99	68	70
1965	69	72	67	61	66	76	51	41	111	214	185	196
1966	164	131	126	99	99	66	50	43	69	86	89	96
1967	88	76	71	74	63	47	38	55	149	113	134	142
1968	107	108	91	92	162	92	70	78	118	130	135	155
1969	145	91	68	78	67	74	42	37	314	137	100	107
1970	105	285	234	180	157	123	232	185	230	208	173	133
1971	169	225	175	99	106	107	80	560	270	207	140	171
1972	172	144	137	111	136	75	77	90	112	140	123	119
1973	110	137	120	170	145	104	103	491	171	152	148	193
1974	154	152	111	148	159	156	103	103	188	177	176	160
1975	154	143	130	130	116	92	93	80	168	167	177	169
1976	131	156	129	103	94	66	46	71	106	113	158	164
1977	118	111	110	99	100	74	81	50	68	68	109	70
1978	78	86	93	91	89	73	61	170	400	197	136	109
1979	109	131	77	90	90	106	101	235	413	200	175	158
1980	150	167	189	194	223	280	316	942	343	205	191	160
1981	126	138	138	111	99	93	67	69	49	119	128	72
1982	71	86	102	107	88	60	41	36	85	177	236	201
1983	193	166	114	159	160	163	391	597	1785	587	281	152
1984	143	103	103	103	192	187	220	539	416	306	272	221
1985	247	204	170	135	129	135	127	239	196	240	166	160

Table A2.35. Monthly 7-day low flows for each year of record at Platteville

Water year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1955	42	41	40	41	48	52	17	17	41	40	46	54
1956	57	53	46	32	29	39	37	26	92	76	64	51
1957	41	63	57	43	50	50	60	300	781	346	195	141
1958	166	163	121	124	142	141	136	282	192	144	103	94
1959	109	93	79	71	96	89	130	160	263	174	170	117
1960	133	154	103	30	80	96	100	120	182	163	111	92
1961	88	104	109	100	108	117	93	96	172	144	106	157
1962	314	270	204	131	154	157	127	64	222	244	146	128
1963	108	99	93	68	78	87	28	28	106	84	94	105
1964	82	96	97	85	72	76	46	40	112	99	69	70
1965	69	75	69	62	67	77	56	44	118	228	197	203
1966	166	140	136	105	103	68	50	45	74	91	90	96
1967	89	77	71	77	64	47	41	55	164	125	132	147
1968	108	111	95	97	164	92	72	82	133	133	139	161
1969	148	92	70	75	67	75	44	41	428	141	103	109
1970	122	293	235	182	157	125	228	202	256	212	179	139
1971	178	231	168	113	113	110	80	592	293	215	147	176
1972	177	147	138	126	143	79	78	98	117	150	132	120
1973	111	138	138	172	147	106	108	437	190	173	153	192
1974	157	154	123	152	164	160	110	112	186	177	177	164
1975	159	147	136	128	121	99	100	95	211	186	183	178
1976	133	158	124	120	100	67	52	70	113	120	160	170
1977	120	115	112	99	100	77	83	50	70	68	118	74
1978	77	87	97	101	90	74	64	146	411	208	150	113
1979	114	132	95	96	97	111	110	231	455	203	184	159
1980	152	175	195	194	229	290	325	1002	413	223	199	165
1981	126	142	145	116	107	97	69	99	54	130	131	79
1982	78	86	100	110	94	61	42	40	97	181	246	202
1983	193	166	133	161	160	166	404	626	1740	650	280	153
1984	145	128	109	107	194	189	224	546	433	320	287	230
1985	263	204	172	143	133	137	128	266	203	246	183	166

Table A2.36. Monthly 1-day low flows for each year of record at Fort Collins.

Water year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1976	4.1	3.1	3.0	2.9	2.8	2.3	2.4	1.8	27.0	21.0	30.0	4.2
1977	2.4	1.6	1.6	2.0	2.4	2.5	2.5	2.1	36.0	10.0	3.0	2.1
1978	1.6	1.5	1.4	1.8	1.7	2.8	2.1	2.5	22.0	5.6	5.5	2.0
1979	1.3	2.7	2.2	2.5	2.6	3.2	2.8	2.3	416.0	7.4	5.2	2.8
1980	3.8	12.0	4.5	3.8	24.0	44.0	66.0	918.0	199.0	11.0	3.2	3.2
1981	5.2	4.7	3.3	3.1	2.7	2.8	2.2	2.7	2.2	2.2	4.5	0.8
1982	4.3	3.8	2.4	2.3	1.8	1.8	3.1	4.7	44.0	9.9	4.4	1.6
1983	1.4	19.0	16.0	1.8	5.1	6.3	81.0	1250.0	3510.0	175.0	86.0	7.8
1984	7.3	18.0	5.1	67.0	101.0	45.0	33.0	189.0	367.0	24.0	14.0	21.0
1985	10.0	51.0	27.0	62.0	25.0	4.3	2.8	36.0	93.0	9.3	2.0	3.9

Table A2.37. Monthly 4-day low flows for each year of record at Fort Collins.

Water year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1976	4.2	3.4	3.2	3.1	2.8	2.4	2.5	1.9	31.7	35.8	47.0	7.7
1977	2.4	1.6	1.7	2.1	2.5	2.8	2.6	2.3	54.0	23.0	4.8	3.9
1978	1.7	1.5	1.5	1.9	1.8	3.0	2.2	2.9	63.3	58.0	12.1	1.9
1979	1.3	2.8	2.3	2.5	2.6	3.2	2.8	23.6	480.3	19.8	10.4	4.8
1980	5.8	20.5	5.9	4.0	26.0	45.0	82.8	1364.3	217.8	18.5	9.1	7.4
1981	6.2	4.8	3.4	3.2	2.8	3.2	2.6	4.0	9.0	26.8	12.2	3.8
1982	4.3	4.3	2.8	2.4	2.3	2.1	3.5	18.7	80.0	45.2	17.8	1.7
1983	1.6	23.8	24.8	5.0	5.7	8.1	87.8	1317.5	3847.5	383.3	105.8	11.3
1984	7.7	27.0	5.1	75.0	107.0	48.3	36.8	346.3	508.0	83.8	54.0	27.0
1985	25.8	56.5	31.0	67.5	26.5	5.2	5.7	35.8	165.5	21.3	5.0	4.3

Table A2.38. Monthly 7-day low flows for each year of record at Fort Collins.

Water year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1976	4.3	3.6	3.2	3.2	2.9	2.6	2.6	2.0	42.0	52.4	54.1	9.4
1977	2.5	1.7	1.7	2.1	2.5	2.8	2.7	3.2	66.9	43.0	7.2	3.8
1978	1.8	1.5	1.6	1.9	1.8	3.1	2.3	3.6	79.7	64.1	18.6	2.0
1979	1.4	2.9	2.4	2.6	2.8	3.3	3.5	21.9	494.4	30.4	12.6	9.7
1980	7.0	25.6	6.9	4.4	27.7	55.1	95.6	1665.3	318.7	18.7	9.1	7.9
1981	8.0	4.9	3.4	3.3	2.9	3.5	2.8	10.7	19.0	31.9	18.1	7.2
1982	4.5	4.5	2.8	2.4	2.5	2.1	3.9	24.7	99.9	76.1	28.5	2.0
1983	1.9	28.0	29.4	11.8	6.5	13.0	106.0	1367.1	3661.4	518.0	135.1	33.7
1984	8.4	34.4	5.3	65.6	111.7	49.1	43.0	462.9	585.3	109.0	88.3	37.7
1985	38.3	67.9	43.7	75.4	30.4	5.5	6.7	55.9	211.0	33.0	13.0	4.8

Table A3.1. Monthly 7-day low flow statistics used to group months into seasons at Englewood.

Month	Season	Flow (cfs) Mean	Median	SD*	Monthly 7Q3	Seasonal 7Q3
Jan	Low	72	75	29	56	45
Feb	Low	76	71	34	58	45
Mar	Low	84	70	41	61	45
Apr	Transition	146	102	116	78	78
May	High	493	229	619	159	80
Jun	High	434	239	511	144	80
Jul	High	268	195	213	137	80
Aug	High	223	206	181	112	80
Sep	Low	99	73	78	56	45
Oct	Low	95	66	97	50	45
Nov	Low	98	75	75	62	45
Dec	Low	82	70	42	62	45

* Standard deviation

Table A3.2. Monthly 7-day low flow statistics used to group months into seasons at Boulder.

Month	Season	Flow (cfs)			Monthly 7Q3	Seasonal 7Q3
		Mean	Median	SD*		
Jan	Low	30	25	19	19	15
Feb	Low	36	32	18	26	15
Mar	Transition	50	57	23	37	28
Apr	Transition	61	55	34	41	28
May	High	109	63	84	57	48
Jun	High	121	110	89	77	48
Jul	High	99	100	31	83	48
Aug	Transition	65	47	33	47	47
Sep	Low	33	31	7	30	15
Oct	Low	33	30	18	24	15
Nov	Low	44	30	31	25	15
Dec	Low	43	36	21	31	15

* Standard deviation

Table A3.3. Monthly 7-day low flow statistics used to group months into seasons at Longmont (flow data based on a regression of daily flows).

Month	Season	Flow (cfs) Mean	Median	SD*	Monthly 7Q3	Seasonal 7Q3
Jan	Low	34	33	16	25	22
Feb	Low	37	33	16	32	22
Mar	Low	35	32	17	26	22
Apr	Low	43	34	32	26	22
May	Transition	120	72	132	51	51
Jun	High	242	206	173	151	69
Jul	High	145	126	74	88	69
Aug	High	92	87	36	63	69
Sep	Transition	60	62	22	40	35
Oct	Transition	52	48	27	29	35
Nov	Transition	48	48	25	28	35
Dec	Low	39	35	17	24	22

* Standard deviation

Table A3.4. Monthly 7-day low flow statistics used to group months into seasons at Fort Collins.

Month	Season	Flow (cfs) Mean	Median	SD*	Monthly 7Q3	Seasonal 7Q3
Jan	Low	17	3	28	3.2	1.6
Feb	Low	19	3	34	3.0	1.6
Mar	Low	14	3	20	3.4	1.6
Apr	Low	27	4	41	3.6	1.6
May	High	362	22	628	10.9	8.0
Jun	High	558	106	1108	80.8	8.0
Jul	High	98	44	150	33.2	8.0
Aug	High	38	18	42	21.6	8.0
Sep	Low	12	7	13	6.9	1.6
Oct	Low	8	4	11	3.9	1.6
Nov	Low	17	5	22	7.2	1.6
Dec	Low	10	3	14	4.0	1.6

* Standard deviation

Table A3.5. Seasonal 7-day low flow frequency statistics at Englewood.

Recurrence Interval (years)	Low flow (cfs)			
	Low (Sep-Mar)	Transition (Apr)	High (May-Aug)	High* (Apr-Aug)
2	54	107	111	78
3	45	78	80	60
5	37	58	60	49
10	30	43	44	40

*Based on two seasons only, low and high.

Table A3.6 Seasonal 7-day low flows for each year of record at Englewood.

Year (ending)	Low flow (cfs)			
	Low (Sep-Mar)	Transition (Apr)	High (May-Aug)	High* (Apr-Aug)
1956	37	42	39	39
1957	15	62	270	62
1958	71	217	53	53
1959	44	121	82	82
1960	33	483	43	43
1961	36	132	130	130
1962	119	286	72	72
1963	32	35	26	26
1964	46	105	72	72
1965	36	87	284	87
1966	66	99	72	72
1967	47	50	86	50
1968	72	97	154	97
1969	46	73	158	73
1970	103	314	220	220
1971	95	114	230	114
1972	66	68	117	68
1973	65	164	268	164
1974	64	321	80	80
1975	53	82	186	82
1976	44	78	100	78
1977	60	102	60	60
1978	50	47	53	47
1979	41	151	105	105
1980	51	175	166	166
1981	48	59	48	48
1982	43	37	79	37
1983	48	405	556	405
1984	76	292	312	292
1985	98	182	277	182

*Based on two seasons only, low and high.

Table A3.7. Seasonal 7-day low flow frequency statistics at Boulder.

Recurrence interval (years)	Low flow (cfs) Low (Sep-May)	Transition (Mar-Apr)	High (May-Jun)	Transition (Aug)
2	19	38	59	55
3	15	28	48	47
5	12	21	38	41
10	9	14	29	36

Table A3.8. Seasonal 7-day low flows for each year of record at Boulder.

Year (ending)	Low flow (cfs) Low (Sep-May)	Transition (Mar-Apr)	High (May-Jun)	Transition (Aug)
1960	24	85	60	134
1961	18	57	102	46
1962	51	57	50	106
1963	15	30	66	40
1964	9	37	61	47
1965	14	27	53	53
1966	24	25	29	47
1967	8	9	19	112
1968	29	59	58	38
1969	16	15	86	46
1970	26	65	61	47

Table A3.9. Seasonal 7-day low flow frequency statistics at Longmont (flow data based on a regression of daily flows).

Recurrence interval (years)	Low flow (cfs) Low (Dec-Apr)	Transition (May)	High (Jun-Aug)	Transition (Sep-Nov)
2	27	74	81	43
3	22	51	69	35
5	17	36	60	29
10	13	26	52	22

Table A3.10. Seasonal 7-day low flows for each year of record at Longmont (flow data based a regression of daily flows).

Year (ending)	Low flow (cfs) Low (Dec-Apr)	Transition (May)	High (Jun-Aug)	Transition (Sep-Nov)
1956	9	47	53	15
1957	12	225	127	12
1958	39	161	63	55
1959	23	126	87	29
1960	8	66	49	46
1961	30	73	79	32
1962	46	100	64	85
1963	13	22	58	31
1964	21	24	46	31
1965	19	71	117	24
1966	19	30	59	48
1967	14	25	104	26
1968	33	67	81	43
1969	18	35	71	30
1970	42	192	98	51
1971	34	317	109	68
1972	29	60	91	52
1973	37	197	117	45
1974	40	90	89	50
1975	35	81	113	54
1976	21	48	84	49
1977	30	30	50	43
1978	24	73	79	33
1979	29	119	85	31
1980	70	663	132	62
1981	31	34	49	51
1982	25	32	55	38
1983	48	301	144	62
1984	40	279	206	49
1985	50	124	100	94

Table A3.11. Seasonal 7-day low flow frequency statistics at Fort Collins.

Recurrence interval (years)	Low flow (cfs) Low season (Sep-Apr)	Low flow (cfs) High season (May-Aug)
2	2.5	13.6
3	2.0	8.0
5	1.6	5.2
10	1.4	3.4

Table A3.12. Seasonal 7-day low flows for each year of record at Fort Collins.

Year (ending)	Low flow (cfs) Low season (Sep-Apr)	Low flow (cfs) High season (May-Aug)
1977	1.7	3.2
1978	1.5	3.6
1979	1.4	12.6
1980	4.4	9.1
1981	2.8	10.7
1982	2.1	24.7
1983	1.9	135.1
1984	5.3	88.3
1985	5.5	13.0

Table A4.1. One-day low-flow excursions at Littleton.

	Number of excursions for a given annual flow*					
Climatic	Acute flows		Chronic flows			
Year (4/1-3/31)	1Q10 (10 cfs)	1Q3 (15 cfs)	7Q10 (12 cfs)	30Q10 (17 cfs)	7Q3 (19 cfs)	30Q3 (27 cfs)
1956	0	9	5	33	51	133
1957	30	106	44	122	161	220
1958	0	0	0	0	0	0
1959	0	0	0	0	1	35
1960	0	0	0	2	2	12
1961	0	0	0	1	1	13
1962	0	0	0	0	0	0
1963	0	12	3	14	16	44
1964	0	5	2	7	14	72
1965	0	2	0	7	20	79
1966	0	0	0	0	0	0
1967	0	0	0	1	1	22
1968	0	0	0	0	0	5
1969	0	2	0	3	5	14
1970	0	0	0	0	0	0
1971	0	0	0	0	0	0
1972	0	1	0	1	1	1
1973	0	0	0	0	0	0
1974	0	0	0	0	0	2
1975	0	0	0	0	1	5
1976	0	0	0	0	0	42
1977	0	0	0	2	3	5
1978	0	0	0	0	0	21
1979	0	8	0	9	11	45
1980	0	3	0	6	7	22
1981	0	0	0	0	0	22
1982	0	41	8	66	74	87
1983	0	0	0	0	10	56
1984	0	0	0	0	0	0
1985	0	0	0	0	0	2
Years with excursions (30 total)	1	10	5	14	17	22
Days with excursions (10958 total)	30	189	62	274	381	959

*Excursion = single 1-day flow below a given level.

Table A4.2. One-day low-flow excursions at Englewood.

Climatic Year (4/1-3/31)	Number of excursions for a given annual flow*					
	Acute flows		Chronic flows			
	1Q10 (24 cfs)	1Q3 (35 cfs)	7Q10 (28 cfs)	30Q10 (36 cfs)	7Q3 (43 cfs)	30Q3 (53 cfs)
1956	0	12	2	16	74	145
1957	41	63	47	69	169	232
1958	0	0	0	0	0	0
1959	0	0	0	0	4	40
1960	0	9	1	9	15	22
1961	0	5	0	6	19	33
1962	0	0	0	0	0	0
1963	0	18	0	18	36	79
1964	7	26	17	28	41	100
1965	0	4	0	8	46	96
1966	0	0	0	0	0	0
1967	0	0	0	0	3	38
1968	0	0	0	0	0	2
1969	0	0	0	0	2	11
1970	0	0	0	0	0	0
1971	0	0	0	0	0	0
1972	0	0	0	0	0	1
1973	0	0	0	0	0	0
1974	0	0	0	0	0	2
1975	0	0	0	0	4	9
1976	0	0	0	0	5	29
1977	0	0	0	0	0	3
1978	0	0	0	0	0	11
1979	0	0	0	0	9	76
1980	0	0	0	0	0	11
1981	0	0	0	0	0	24
1982	0	0	0	0	8	48
1983	0	1	0	4	6	24
1984	0	0	0	0	0	0
1985	0	0	0	0	0	0
Years with excursions (30 total)	2	8	4	8	15	22
Days with excursions (10958 total)	48	138	67	158	441	1036

*Excursion = single 1-day flow below a given level.

Table A4.3. One-day low flow-excursions at Henderson.

Climatic Year (4/1-3/31)	Number of excursions for a given annual flow*					
	Acute flows		Chronic flows			
	1Q10 (17 cfs)	1Q3 (40 cfs)	7Q10 (26 cfs)	30Q10 (46 cfs)	7Q3 (61 cfs)	30Q3 (89 cfs)
1956	0	13	1	44	148	192
1957	18	47	29	55	104	159
1958	0	2	1	3	4	20
1959	0	0	0	0	48	192
1960	0	3	1	4	22	141
1961	0	0	0	0	2	161
1962	0	0	0	0	2	3
1963	12	29	21	32	51	184
1964	0	19	5	25	42	145
1965	0	4	2	7	17	88
1966	1	5	2	6	7	25
1967	0	0	0	0	1	9
1968	0	0	0	0	0	1
1969	0	0	0	0	0	52
1970	0	0	0	0	1	16
1971	0	0	0	0	0	0
1972	0	0	0	0	0	0
1973	0	0	0	0	0	0
1974	0	0	0	0	0	0
1975	0	0	0	0	0	0
1976	0	0	0	0	0	1
1977	0	0	0	0	0	1
1978	0	1	0	2	5	7
1979	0	0	0	0	4	6
1980	0	0	0	0	0	0
1981	0	0	0	0	0	0
1982	0	0	0	0	0	12
1983	0	0	0	0	0	1
1984	0	0	0	0	0	0
1985	0	0	0	0	0	0
Years with excursions (30 total)	3	9	8	9	15	21
Days with excursions (10958 total)	31	123	64	178	459	1416

*Excursion = single 1-day flow below a given level.

Table A4.4. One-day low-flow excursions at Boulder.

Climatic Year (4/1-3/31)	Number of excursions for a given annual flow* Acute flows 1Q10 (5 cfs)	1Q3 (8 cfs)	7Q10 (9 cfs)	Chronic flows 7Q3 (13 cfs)	30Q10 (14 cfs)	30Q3 (20 cfs)
1960	0	0	0	0	0	0
1961	0	0	0	0	0	13
1962	0	0	0	0	0	0
1963	0	0	0	0	3	32
1964	0	5	10	17	26	44
1965	0	0	0	4	5	25
1966	0	0	0	0	0	2
1967	2	6	11	34	67	96
1968	1	3	4	8	10	14
1969	0	0	0	0	5	24
1970	0	0	0	0	0	1
Years with excursions (11 total)	2	3	3	4	6	9
Days with excursions (4004 total)	3	14	25	63	116	251

*Excursion = single 1-day flow below a given level.

Table A4.5. One-day low-flow excursions at Lyons.

	Number of excursions for a given annual flow*					
Climatic	Acute flows			Chronic flows		
Year (4/1-3/31)	1Q10 (0.8cfs)	1Q3 (2.2cfs)	7Q10 (1.3cfs)	30Q10 (3.6cfs)	7Q3 (3.8cfs)	30Q3 (6.0cfs)
1956	2	12	2	20	20	34
1957	22	24	24	30	30	106
1958	1	1	1	22	22	30
1959	6	31	31	33	33	41
1960	0	0	0	6	7	13
1961	0	7	4	20	22	41
1962	0	0	0	0	0	0
1963	0	0	0	2	2	26
1964	1	17	12	27	27	58
1965	0	6	0	10	11	60
1966	0	0	0	0	0	16
1967	0	1	0	10	10	37
1968	0	0	0	0	0	0
1969	0	0	0	0	0	6
1970	0	0	0	0	0	11
1971	0	0	0	0	0	0
1972	0	0	0	0	0	2
1973	0	0	0	0	0	0
1974	0	0	0	1	1	10
1975	0	0	0	0	0	4
1976	0	0	0	0	0	1
1977	0	0	0	2	4	35
1978	0	0	0	0	0	2
1979	0	0	0	0	0	0
1980	0	0	0	0	0	0
1981	0	0	0	0	0	0
1982	0	0	0	5	5	8
1983	0	0	0	0	0	1
1984	0	0	0	0	0	0
1985	0	0	0	0	0	0
Years with excursions (30 total)	5	8	6	13	13	21
Days with excursions (10958 total)	32	99	74	188	194	542

*Excursion = single 1-day flow below a given level.

Table A4.6. One-day low-flow excursions for Longmont (based on a regression of daily flows).

Climatic	Number of excursions for a given annual flow*					
	Acute flows		Chronic flows			
Year (4/1-3/31)	1Q10 (10 cfs)	1Q3 (15 cfs)	7Q10 (12 cfs)	30Q10 (18 cfs)	7Q3 (20 cfs)	30Q3 (26 cfs)
1956	6	73	22	124	165	209
1957	4	52	15	110	159	208
1958	0	2	1	3	4	4
1959	0	0	0	1	1	18
1960	7	9	8	10	10	17
1961	0	0	0	1	1	3
1962	0	0	0	0	0	1
1963	0	0	0	1	3	18
1964	1	11	4	18	19	75
1965	0	0	0	2	19	118
1966	0	0	0	0	0	6
1967	0	10	0	37	41	107
1968	0	4	2	11	12	18
1969	0	0	0	0	1	42
1970	0	0	0	3	6	17
1971	0	0	0	0	0	0
1972	0	0	0	0	0	0
1973	0	0	0	0	0	1
1974	0	0	0	0	0	1
1975	0	0	0	0	0	0
1976	0	1	0	1	1	13
1977	0	0	0	1	2	17
1978	0	0	0	0	0	21
1979	0	0	0	0	0	4
1980	0	0	0	0	0	0
1981	0	0	0	0	0	0
1982	0	0	0	0	0	8
1983	0	0	0	0	0	10
1984	0	0	0	0	0	0
1985	0	0	0	0	0	0
Years with excursions (30 total)	4	8	6	14	15	23
Days with excursions (10958 total)	18	162	52	323	444	936

*Excursion = single 1-day flow below a given level.

Table A4.7. One-day low-flow excursions at Platteville.

	Number of excursions for a given annual flow*					
Climatic	Acute flows		Chronic flows			
Year (4/1-3/31)	1Q10 (27 cfs)	1Q3 (42 cfs)	7Q10 (31 cfs)	30Q10 (43 cfs)	7Q3 (50 cfs)	30Q3 (67 cfs)
1956	20	76	27	81	147	273
1957	7	47	12	51	79	220
1958	0	0	0	0	1	2
1959	0	0	0	0	0	3
1960	1	9	5	9	9	11
1961	0	0	0	0	0	2
1962	0	0	0	0	0	0
1963	0	0	0	0	0	8
1964	0	26	14	26	29	33
1965	0	5	0	9	20	61
1966	0	2	0	4	8	17
1967	0	0	0	1	20	74
1968	0	4	0	5	14	31
1969	0	0	0	0	0	2
1970	0	4	0	4	8	21
1971	0	0	0	0	0	0
1972	0	0	0	0	0	0
1973	0	0	0	0	0	0
1974	0	0	0	0	0	0
1975	0	0	0	0	0	0
1976	0	0	0	0	0	5
1977	0	0	0	0	4	21
1978	0	0	0	0	5	23
1979	0	0	0	0	0	6
1980	0	0	0	0	0	0
1981	0	0	0	0	0	0
1982	0	0	0	0	3	17
1983	0	11	0	12	22	41
1984	0	0	0	0	0	0
1985	0	0	0	0	0	0
Years with excursions (30 total)	3	9	4	10	14	20
Days with excursions (10958 total)	28	184	58	202	369	871

*Excursion = single 1-day flow below a given level.

Table A4.8. One-day low-flow excursions at Fort Collins.

Climatic Year (4/1-3/31)	Number of excursions for a given annual flow*					
	Acute flows		Chronic flows			
	1Q10 (0.9cfs)	1Q3 (1.5cfs)	7Q10 (1.4cfs)	30Q10 (1.4cfs)	7Q3 (2.0cfs)	30Q3 (2.9cfs)
1977	0	0	0	0	17	130
1978	0	1	0	0	68	150
1979	0	6	3	3	12	82
1980	0	0	0	0	0	3
1981	0	0	0	0	0	4
1982	3	3	3	3	9	62
1983	0	1	0	0	10	16
1984	0	0	0	0	0	0
1985	0	0	0	0	0	0
Years with excursions (9 total)	1	4	2	2	5	7
Days with excursions (3287 total)	3	11	6	6	116	442

*Excursion = single 1-day flow below a given level.

Table A4.9. Four-day low-flow excursions at Henderson.

Climatic Year (4/1-3/31)	Chronic flows 7Q10 (26 cfs)	30Q10 (46 cfs)	7Q3 (61 cfs)	30Q3 (89 cfs)
1956	0	54	137	187
1957	0	25	56	156
1958	0	1	3	20
1959	0	0	39	189
1960	0	5	18	134
1961	0	0	0	164
1962	0	0	0	2
1963	21	33	53	199
1964	4	23	37	143
1965	0	3	19	87
1966	1	5	6	23
1967	0	0	0	2
1968	0	0	0	0
1969	0	0	0	52
1970	0	0	0	13
1971	0	0	0	0
1972	0	0	0	0
1973	0	0	0	0
1974	0	0	0	0
1975	0	0	0	0
1976	0	0	0	0
1977	0	0	0	0
1978	0	0	1	5
1979	0	0	2	5
1980	0	0	0	0
1981	0	0	0	0
1982	0	0	0	10
1983	0	0	0	0
1984	0	0	0	0
1985	0	0	0	0
Years with excursions (30 total)	3	8	11	17
Mov. avgs. with excs. (10868) total)	26	149	374	1390

*Excursion = single 4-day flow below a given level.

Table A4.10. Thirty-day low-flow excursions at Henderson.

Climatic Year (4/1-3/31)	Chronic flows 7Q10 (26 cfs)	30Q10 (46 cfs)	7Q3 (61 cfs)	30Q3 (89 cfs)
1956	0	43	112	156
1957	0	35	85	139
1958	0	0	0	0
1959	0	0	28	150
1960	0	0	9	117
1961	0	0	0	142
1962	0	0	0	0
1963	11	33	48	189
1964	0	10	34	109
1965	0	0	0	54
1966	0	0	0	0
1967	0	0	0	0
1968	0	0	0	0
1969	0	0	0	14
1970	0	0	0	0
1971	0	0	0	0
1972	0	0	0	0
1973	0	0	0	0
1974	0	0	0	0
1975	0	0	0	0
1976	0	0	0	0
1977	0	0	0	0
1978	0	0	0	0
1979	0	0	0	0
1980	0	0	0	0
1981	0	0	0	0
1982	0	0	0	0
1983	0	0	0	0
1984	0	0	0	0
1985	0	0	0	0
Years with excursions (30 total)	1	4	6	9
Mov. avgs. with excs. (10088) total)	11	122	316	1070

*Excursion = single 30-day flow below a given level.

Table A5.1. Run lengths of low-flow events for the period of record at Littleton (1956-1985).

1Q10 (10 cfs)		1Q3 (15 cfs)		7Q10 (12 cfs)		7Q3 (19 cfs)		30Q10 (17 cfs)		30Q3 (27 cfs)	
Run length (days)	Number of runs	Run length (days)	Number of runs	Run length (days)	Number of runs	Run length (days)	Number of runs	Run length (days)	Number of runs	Run length (days)	Number of runs
1	1	1	14	1	3	1	31	1	21	1	43
2	1	2	6	2	4	2	12	2	7	2	21
4	1	3	1	3	2	3	7	3	4	3	17
23	1	6	2	4	1	4	3	4	1	4	8
		8	2	7	1	5	2	6	4	5	6
		11	2	8	1	6	4	9	2	6	7
		12	1	25	1	7	1	13	1	7	6
		16	1			9	2	14	1	8	5
		25	1			10	1	19	1	9	3
		58	1			14	2	27	1	10	3
						19	1	28	1	1	1
						23	1	39	1	13	2
						31	1	50	1	14	1
						42	1			15	1
						79	1			16	3
										17	3
										18	1
										19	1
										20	1
										22	1
										28	1
										35	1
										46	1
										50	1
										51	1
										129	1

Table A5.2. Run lengths of low-flow events for the period of record at Englewood (1956-1985).

1Q10 (24 cfs)		1Q3 (35 cfs)		7Q10 (28 cfs)		7Q3 (43 cfs)		30Q10 (36 cfs)		30Q3 (53 cfs)	
Run length (days)	Number of runs	Run length (days)	Number of runs	Run length (days)	Number of runs	Run length (days)	Number of runs	Run length (days)	Number of runs	Run length (days)	Number of runs
1	4	1	11	1	10	1	26	1	16	1	41
2	2	2	8	2	2	2	19	2	9	2	18
4	2	3	5	5	1	3	12	3	7	3	15
32	1	4	2	8	1	4	4	4	2	4	7
		6	1	41	1	5	6	5	1	5	12
		7	1			6	4	6	1	6	8
		9	1			8	3	9	2	7	5
		13	2			9	1	13	1	8	2
		52	1			10	2	53	1	9	4
						11	1			10	1
						14	1			11	4
						16	1			12	3
						18	1			13	6
						33	1			14	3
						35	1			15	2
						38	1			16	1
						54	1			17	1
										18	1
										19	2
										22	1
										34	1
										55	1
										71	1
										137	1
										51	1
										129	1

Table A5.3. Run lengths of low-flow events for the period of record at Henderson (1956-1985).

1Q10 (17 cfs)		1Q3 (40 cfs)		7Q10 (26 cfs)		7Q3 (61 cfs)		30Q10 (46 cfs)		30Q3 (89 cfs)	
Run length (days)	Number of runs	Run length (days)	Number of runs	Run length (days)	Number of runs	Run length (days)	Number of runs	Run length (days)	Number of runs	Run length (days)	Number of runs
1	9	1	7	1	10	1	14	1	16	1	26
2	3	2	2	2	2	2	9	2	9	2	18
3	1	3	4	5	2	3	6	3	6	3	12
7	1	4	2	6	1	4	6	4	3	4	7
9	1	5	1	7	1	5	1	5	3	5	5
10	1	6	1	18	1	6	2	6	3	6	3
		16	2	20	1	7	1	7	1	7	2
		17	1	107	1	8	2	11	1	8	4
		20	1			11	1	18	2	9	4
						12	1	19	1	10	2
						13	1	20	1	11	5
						15	1	28	1	12	1
						19	1	37	1	13	2
						20	1			14	2
						23	1			15	3
						37	1			16	4
										20	1
										21	1
										25	1
										29	1
										33	1
										37	1
										78	1
										87	1
										108	1
										138	1
										203	1

Table A5.4. Run lengths of low-flow events for the period of record at Boulder (1961-1970).

1Q10 (5 cfs)		1Q3 (10 cfs)		7Q10 (8 cfs)		7Q3 (13 cfs)		30Q10 (14 cfs)		30Q3 (20 cfs)	
Run length (days)	Number of runs	Run length (days)	Number of runs	Run length (days)	Number of runs	Run length (days)	Number of runs	Run length (days)	Number of runs	Run length (days)	Number of runs
1	1	1	3	1	5	1	6	1	8	1	16
2	1	2	1	2	3	2	3	2	4	2	7
3	1	4	1	3	1	4	4	3	1	3	3
7	1	5	1	5	1	6	3	4	2	4	2
9	1			6	1	8	1	6	4	5	3
						9	1	9	1	6	2
								15	1	8	1
								16	1	9	1
										10	1
										11	3
										13	1
										17	1
										43	1

Table A5.5. Run lengths of low-flow events for the period of record at Lyons (1956-1985).

1Q10 (0.8 cfs)		1Q3 (2.2 cfs)		7Q10 (1.3 cfs)		7Q3 (3.8 cfs)		30Q10 (3.6 cfs)		30Q3 (6.0 cfs)	
Run length (days)	Number of runs	Run length (days)	Number of runs	Run length (days)	Number of runs	Run length (days)	Number of runs	Run length (days)	Number of runs	Run length (days)	Number of runs
1	3	1	5	1	4	1	12	1	11	1	51
2	1	3	2	2	4	2	8	2	8	2	23
6	1	4	2	8	1	3	2	3	2	3	14
9	1	5	1	9	2	4	2	4	3	4	8
13	1	6	1	14	1	5	2	5	4	5	2
		9	2	22	1	7	1	8	1	6	4
		14	1			8	1	10	2	7	2
		15	1			10	2	11	1	8	1
		22	1			11	1	13	1	9	2
						12	1	16	3	10	3
						13	1	23	1	11	2
						16	3			12	1
						23	1			15	1
										16	2
										18	1
										21	2
										23	1
										24	1
										29	1
										50	1

Table A5.6. Run lengths of low-flow events for the period of record at Longmont (based on a regression of daily flows, 1956-1985).

1Q10 (10 cfs)		1Q3 (15 cfs)		7Q10 (12 cfs)		7Q3 (20 cfs)		30Q10 (18 cfs)		30Q3 (26 cfs)	
Run length (days)	Number of runs	Run length (days)	Number of runs	Run length (days)	Number of runs	Run length (days)	Number of runs	Run length (days)	Number of runs	Run length (days)	Number of runs
1	3	1	5	1	7	1	19	1	21	1	30
2	1	2	3	2	6	2	7	2	7	2	11
6	1	3	4	3	2	3	4	3	4	3	7
7	1	4	6	4	1	4	2	4	1	4	11
		5	1	8	1	5	2	5	1	5	5
		6	2	15	1	6	3	7	2	6	5
		7	2			7	1	9	1	7	3
		9	1			10	1	10	3	8	3
		10	1			12	1	11	2	9	3
		31	1			14	1	12	1	10	3
						15	2	16	1	11	1
						17	1	23	1	12	5
						23	1	25	1	13	1
						24	1	31	1	16	1
						29	1	76	1	18	2
						31	1			21	1
						58	1			22	1
						114	1			27	1
										30	1
										32	2
										38	1
										43	1
										45	1
										111	1
										116	1

Table A5.7. Run lengths of low-flow events for the period of record at Platteville (1956-1985).

1Q10 (27 cfs)		1Q3 (42 cfs)		7Q10 (32 cfs)		7Q3 (50 cfs)		30Q10 (43 cfs)		30Q3 (67 cfs)	
Run length (days)	Number of runs	Run length (days)	Number of runs	Run length (days)	Number of runs	Run length (days)	Number of runs	Run length (days)	Number of runs	Run length (days)	Number of runs
1	2	1	5	1	2	1	9	1	7	1	23
2	2	2	7	3	1	2	10	2	4	2	14
5	1	3	3	4	1	3	4	3	4	3	7
17	1	4	8	5	2	4	4	4	6	4	6
9	1	5	3	7	1	5	4	5	3	5	5
		6	1	13	1	6	1	6	2	6	4
		7	1	19	1	7	3	7	1	7	4
		8	1			8	1	8	2	8	1
		9	1			9	2	9	2	9	3
		13	1			10	2	13	1	10	2
		15	1			11	1	19	1	11	3
		25	1			12	2	25	1	12	3
		26	1			13	2	26	1	13	2
						17	1			15	1
						18	1			16	1
						20	1			17	1
						27	1			23	1
						29	1			26	1
						47	1			30	1
										31	1
										33	1
										34	1
										40	1
										42	1
										50	1
										52	1
										53	1
										81	1

Table A5.8. Run lengths of low-flow events for the period of record at Fort Collins

1Q10 (0.9 cfs)		1Q3 (1.5 cfs)		7Q10 (1.4 cfs)		7Q3 (2.0 cfs)		30Q10 (1.4 cfs)		30Q3 (2.9 cfs)	
Run length (days)	Number of runs	Run length (days)	Number of runs	Run length (days)	Number of runs	Run length (days)	Number of runs	Run length (days)	Number of runs	Run length (days)	Number of runs
1	1	1	4	1	1	1	9	1	1	1	17
2	1	2	1	2	1	2	3	2	1	2	8
		5	1	3	1	3	4	3	1	3	3
						4	1	26	1	4	4
						6	3			5	2
						9	1			6	2
						10	2			7	2
						12	1			8	2
										10	2
										12	3
										13	1
										17	1
										23	1
										24	1
										40	1
										70	1
										93	1

Table A5.9. A comparison of the 7Q10 statistic estimated using the Log Pearson Type III distribution and the normal distribution.

Site	7Q10 Log Pearson Type III	Normal
Littleton	12	10
Englewood	28	26
Henderson	26	10
Boulder	8	5
Lyons	1.3	0.7
Longmont	12	12
Platteville	31	29
Fort Collins	1.4	1.0

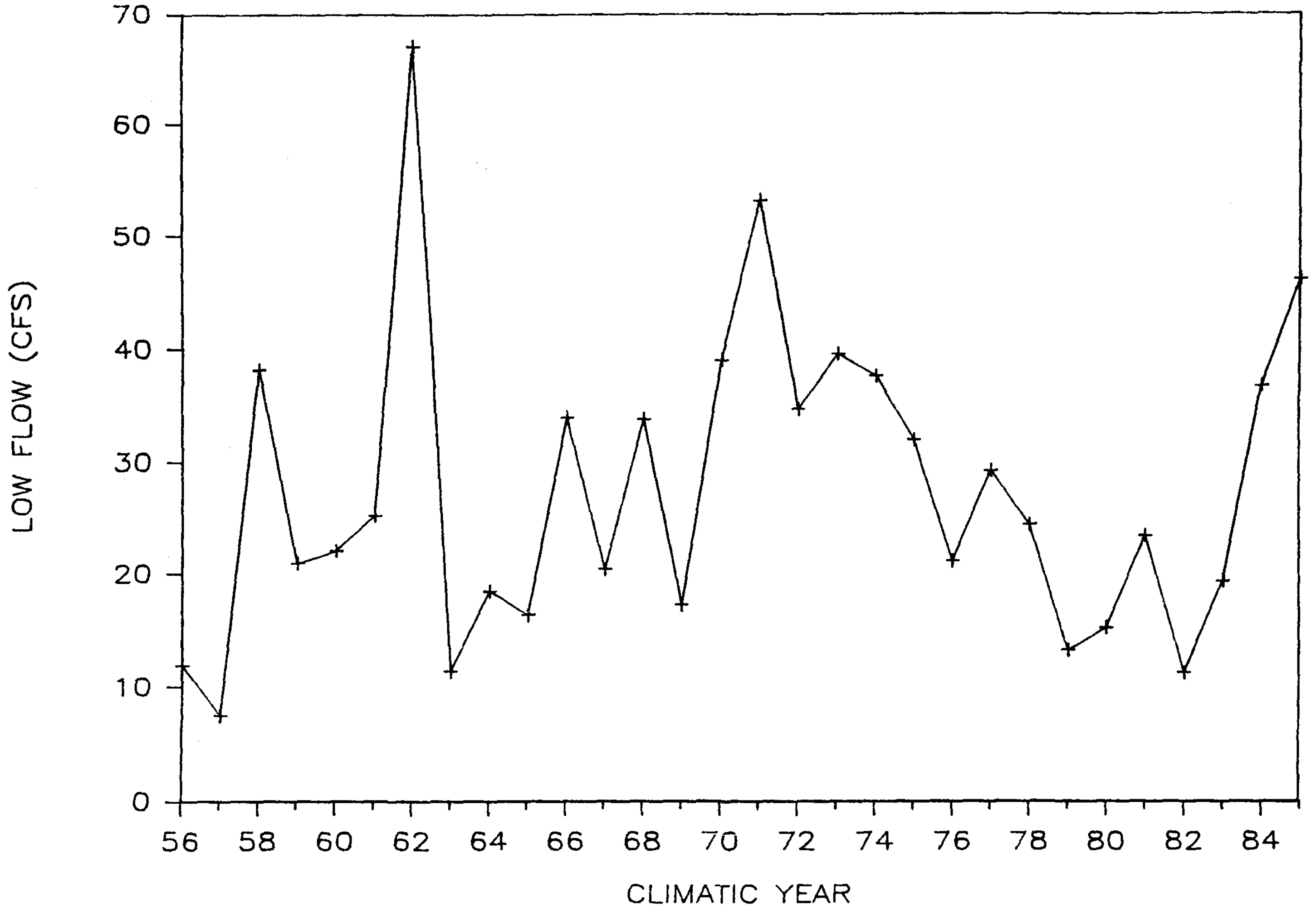

Figure A1.1 Annual 7-day low flows versus time at Littleton.

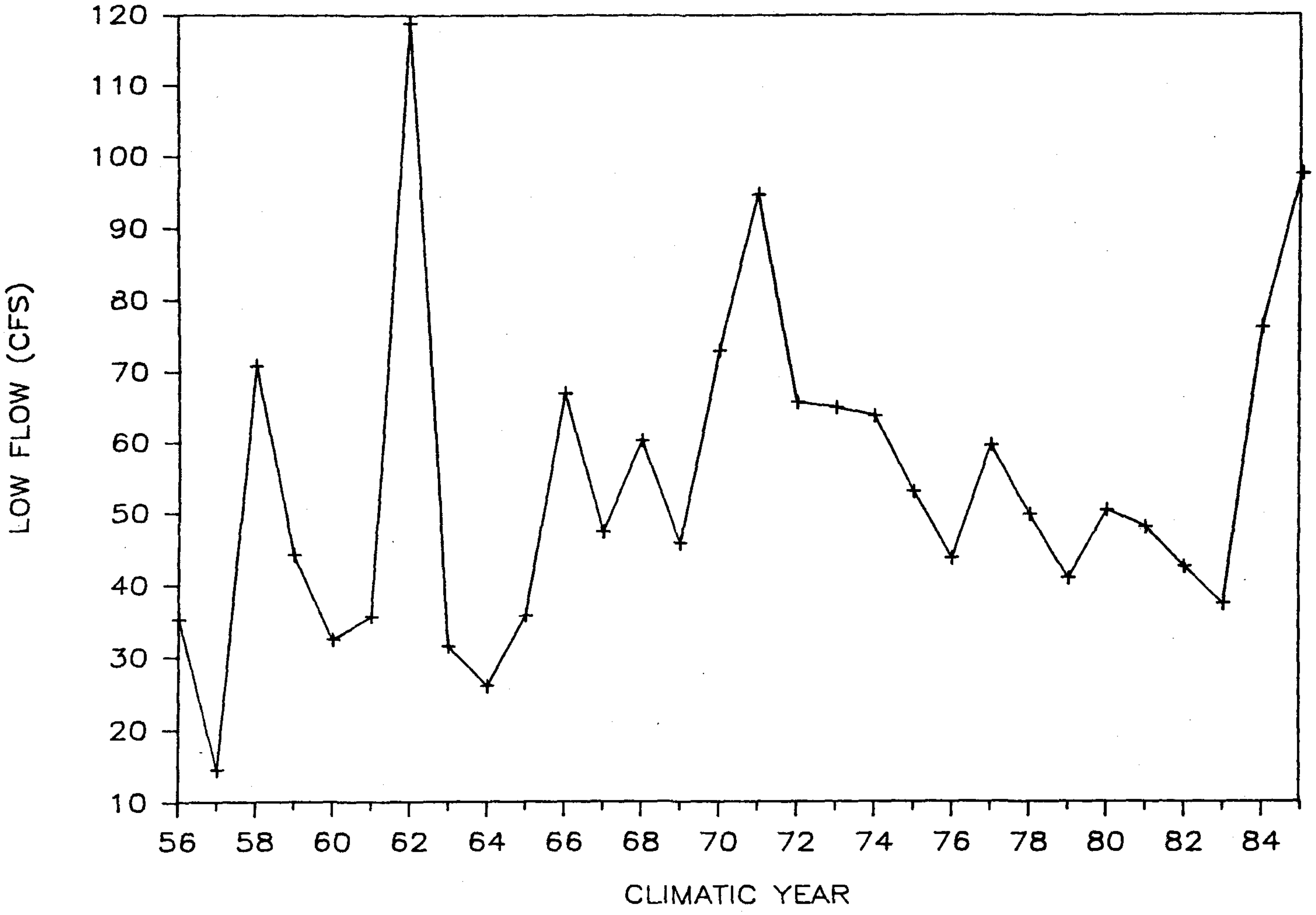

Figure A1.2 Annual 7-day low flows versus time at Englewood.

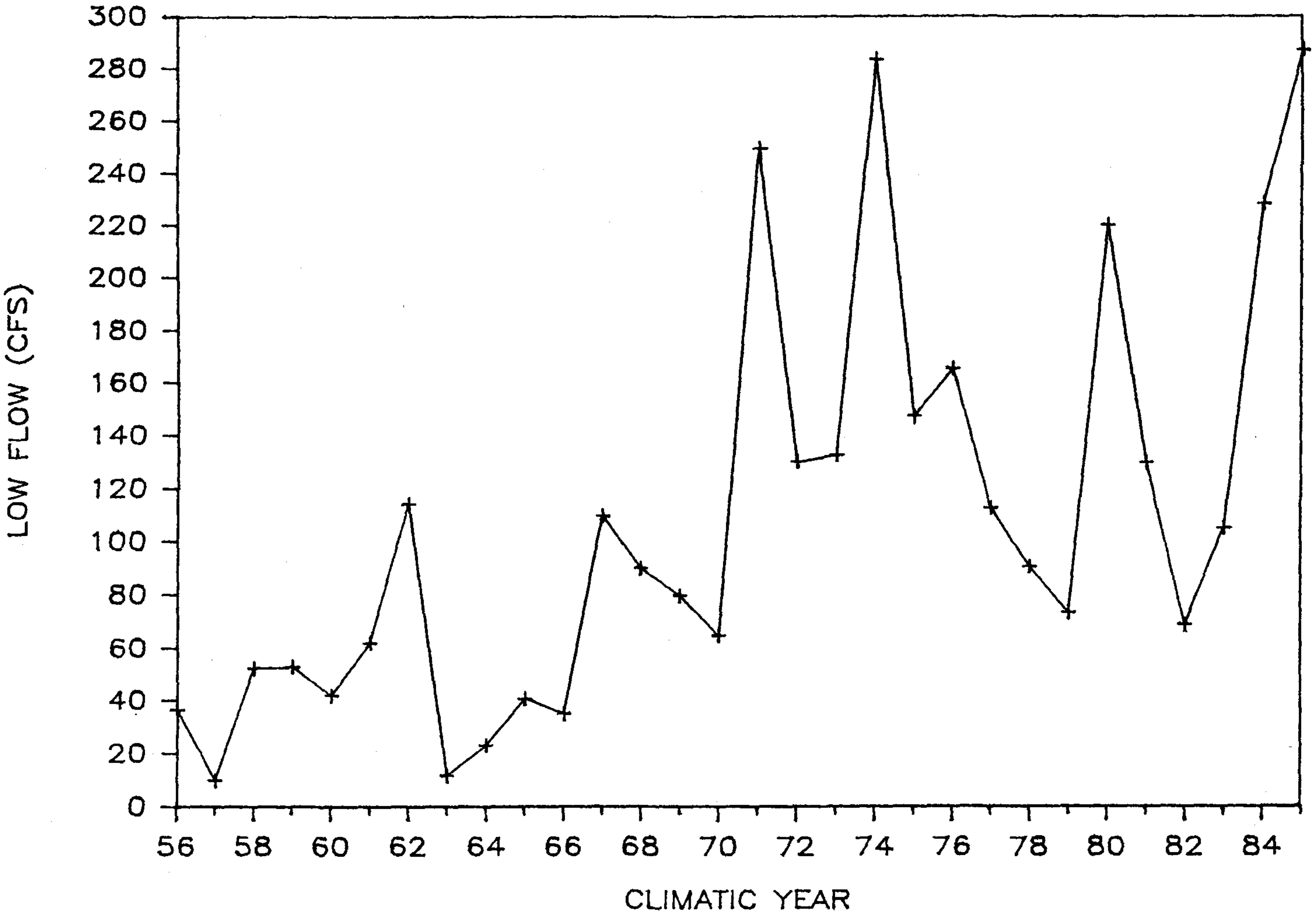

Figure A1.3 Annual 7-day low flows versus time at Henderson.

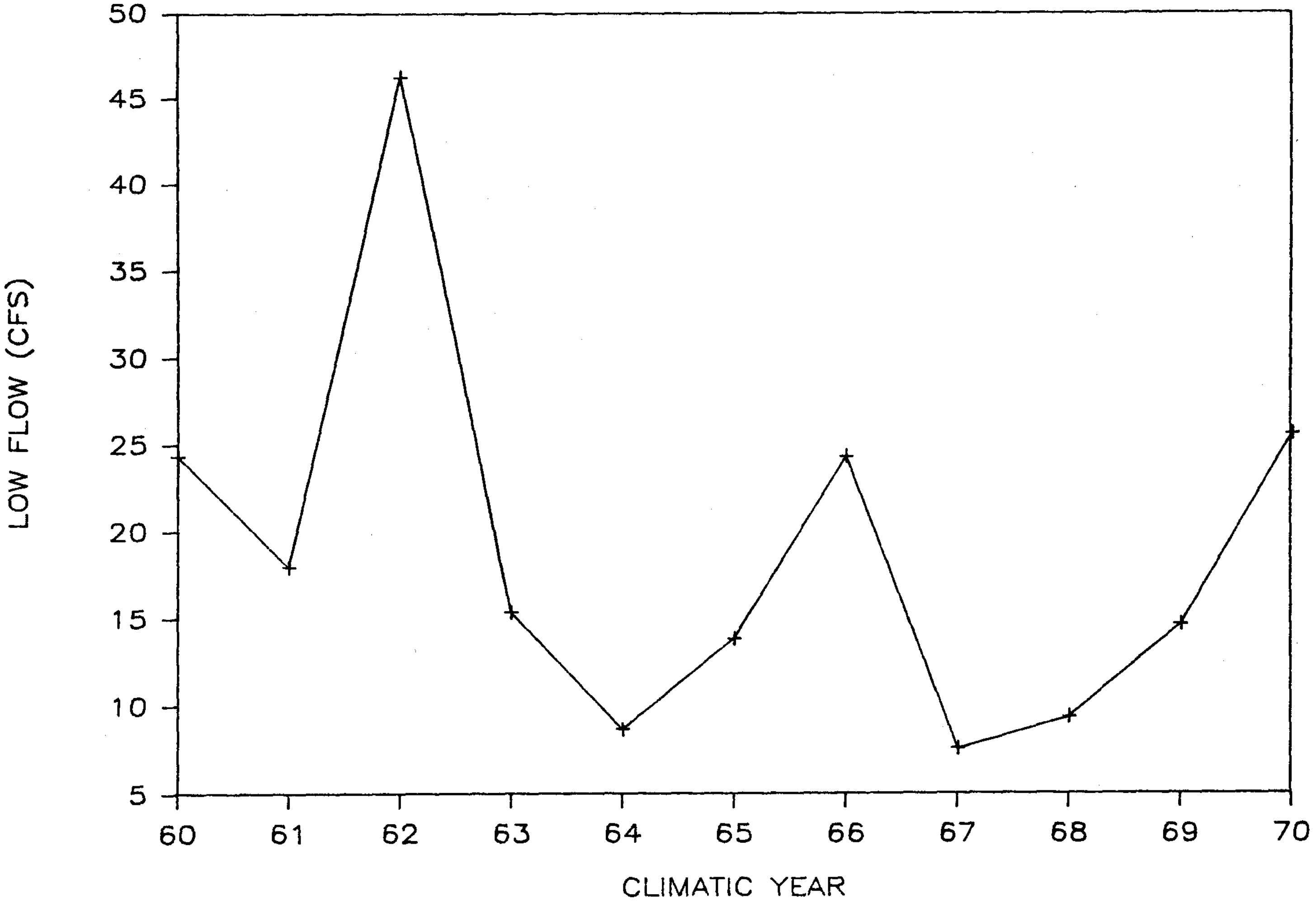

Figure A1.4 Annual 7-day low flows versus time at Boulder.

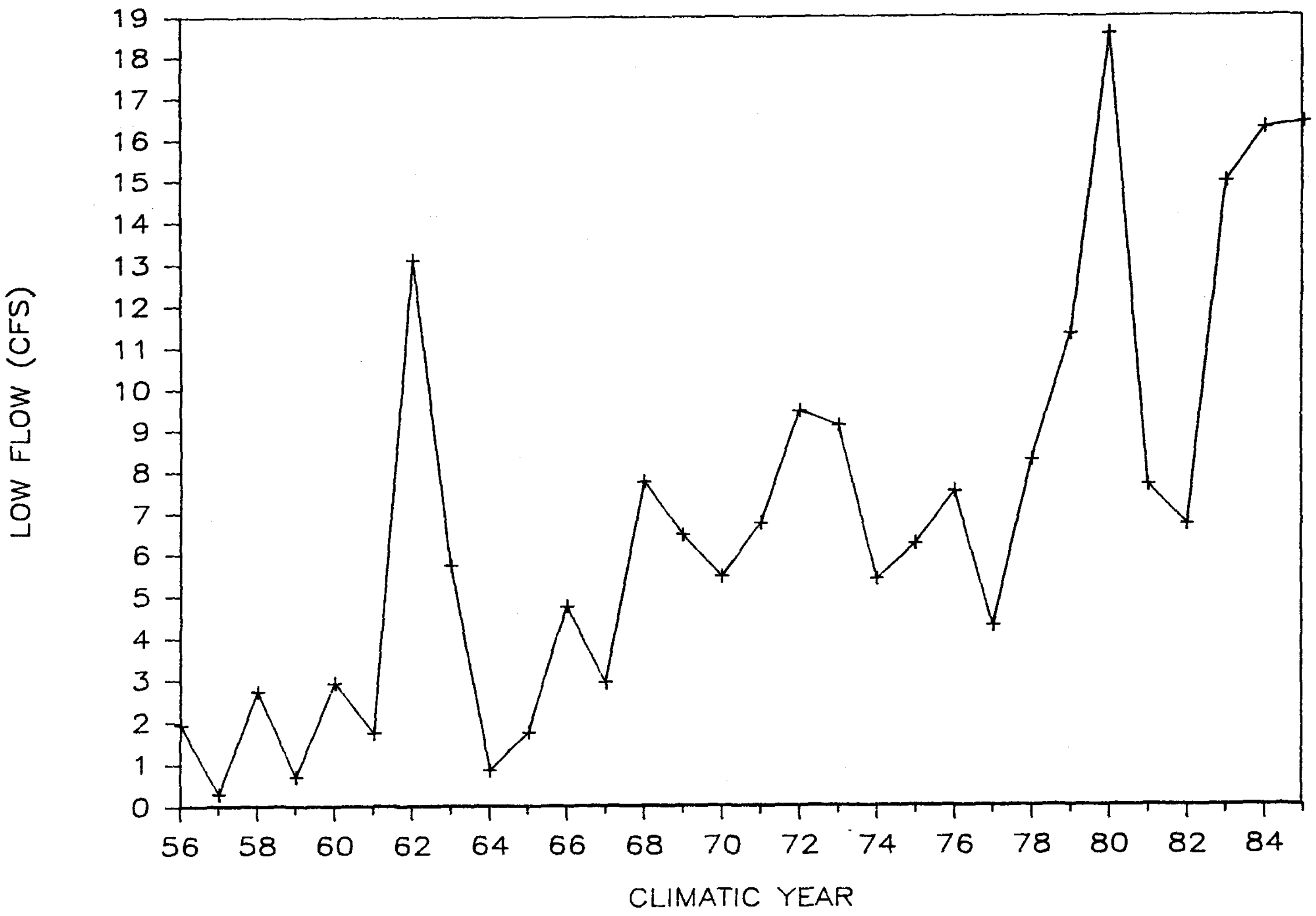

Figure A1.5 Annual 7-day low flows versus time at Lyons.

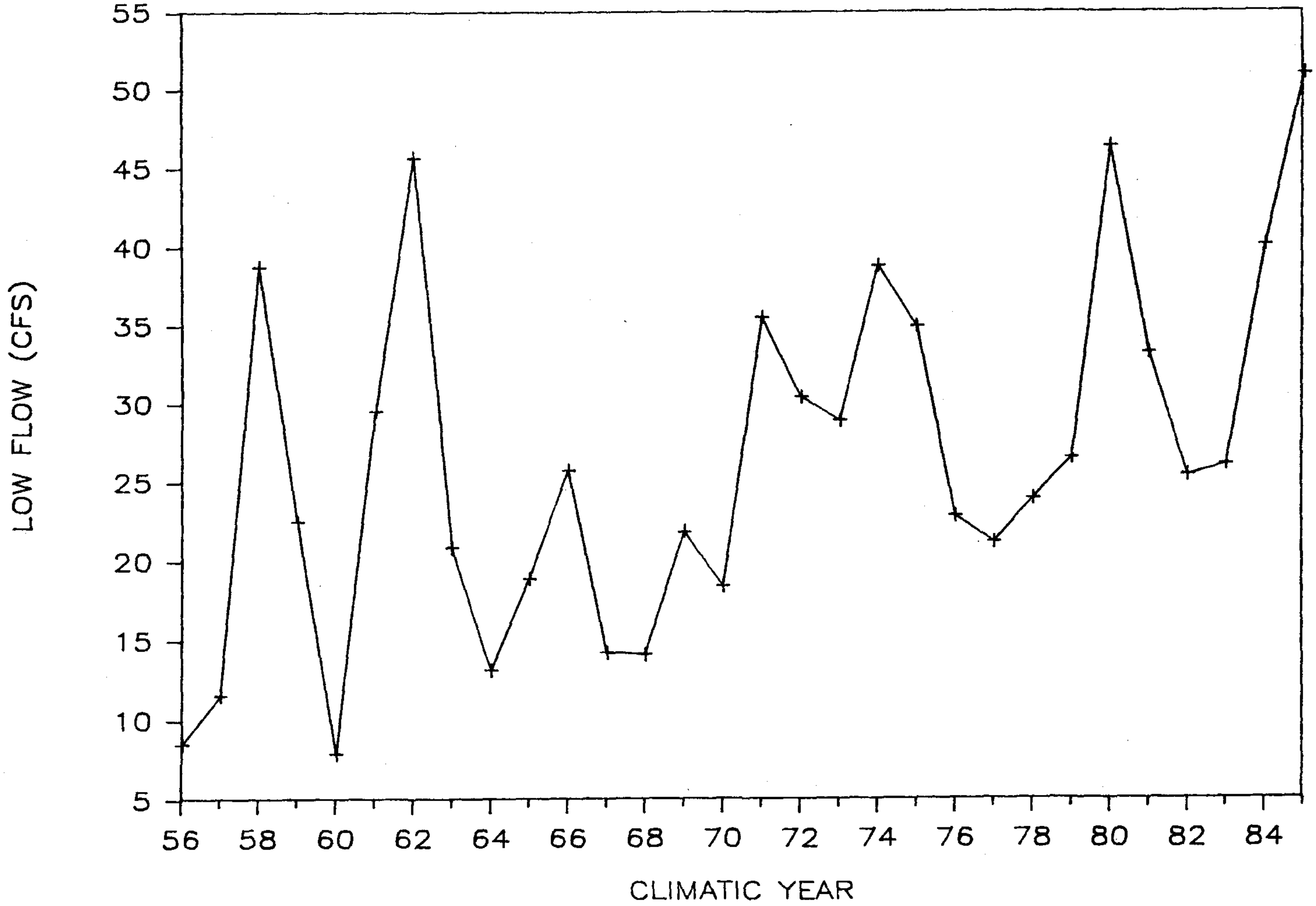

Figure A1.6 Annual 7-day low flows versus time at Longmont.

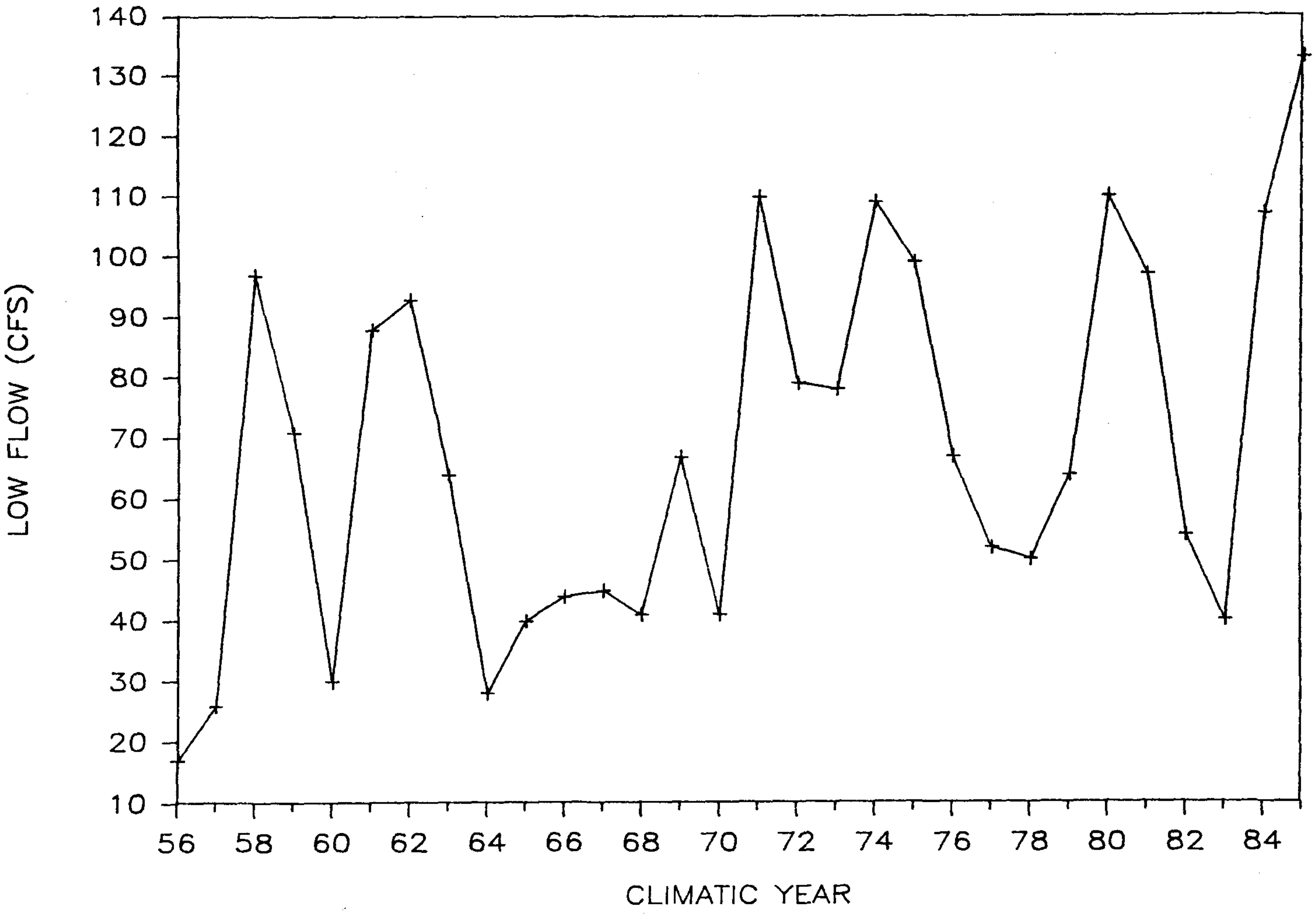

Figure A1.7 Annual 7-day low flows versus time at Platteville.

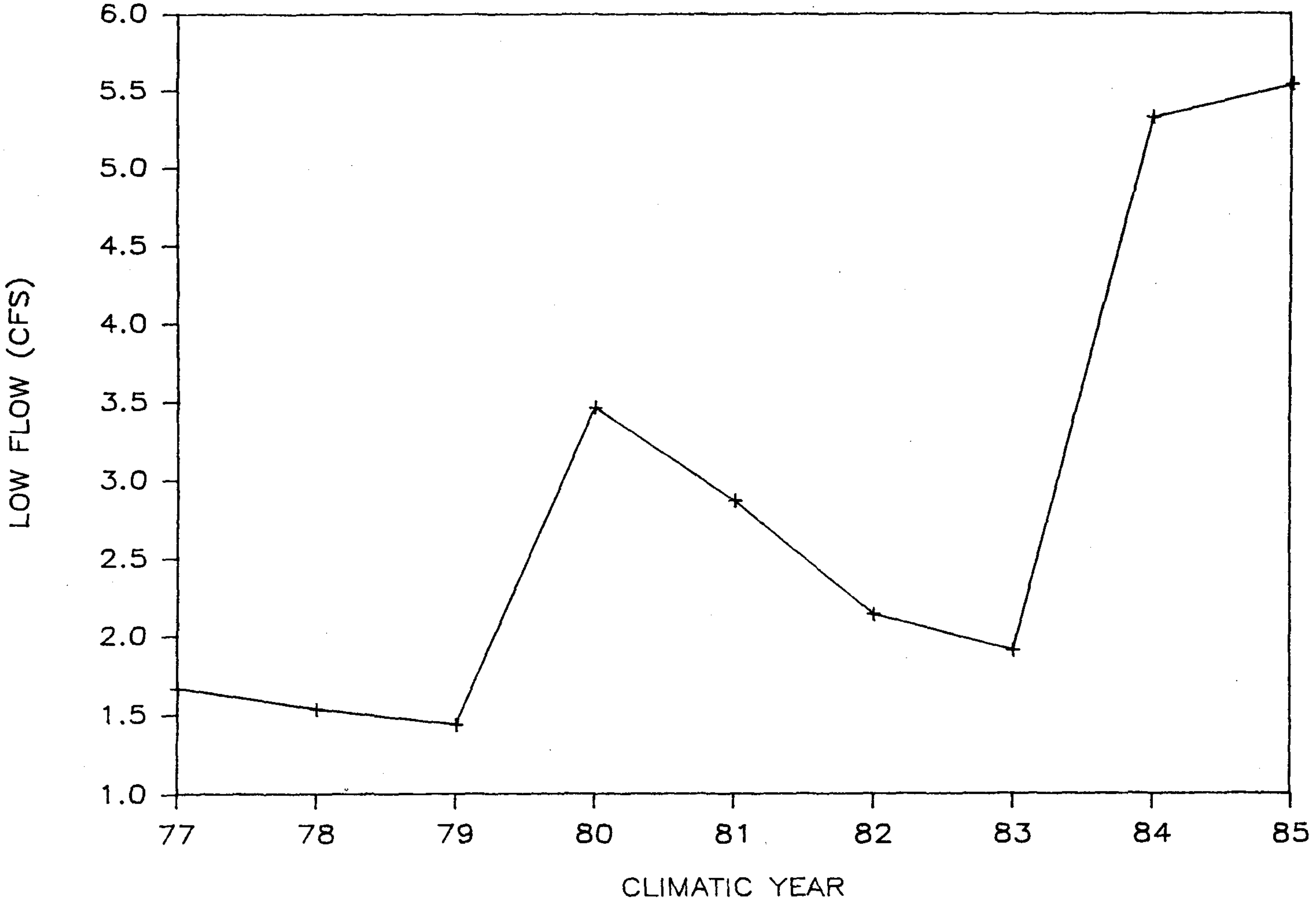

Figure A1.8 Annual 7-day low flows versus time at Fort Collins.

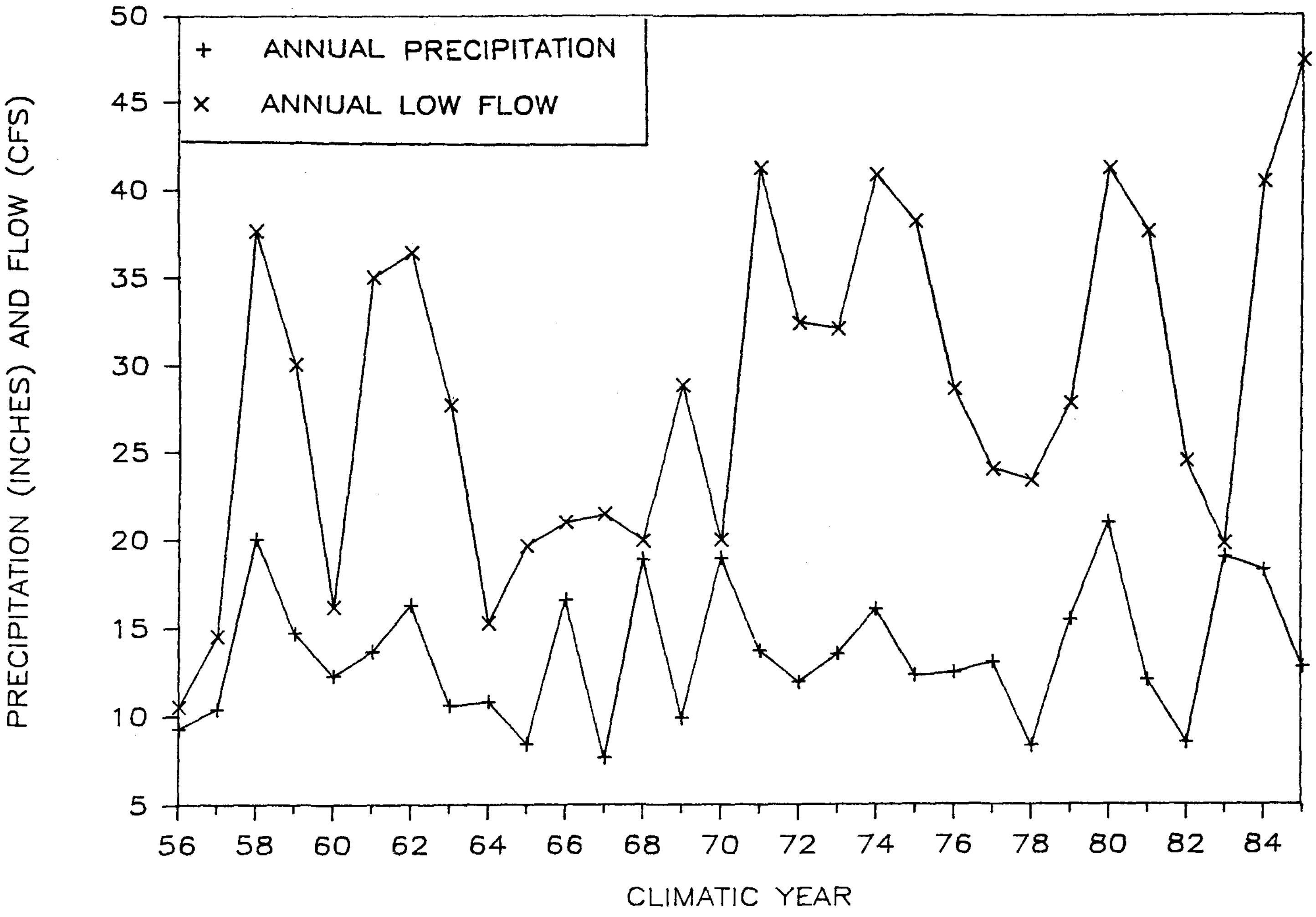

Figure A1.9 Annual precipitation and 7-day low flows at Longmont.

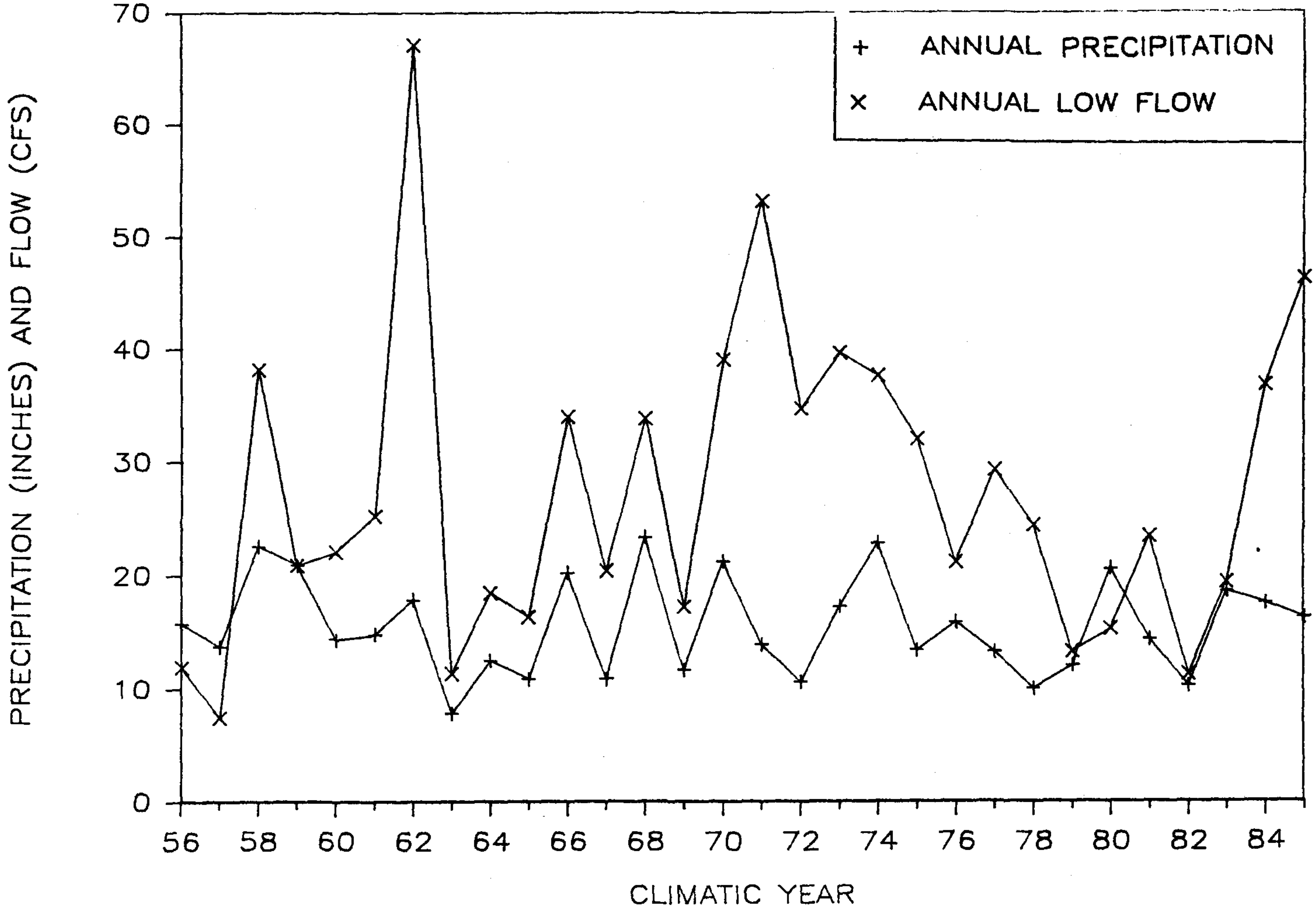

Figure A1.10 Annual precipitation and 7-day low flows at Littleton (precipitation records from Stapleton Airport, Denver).

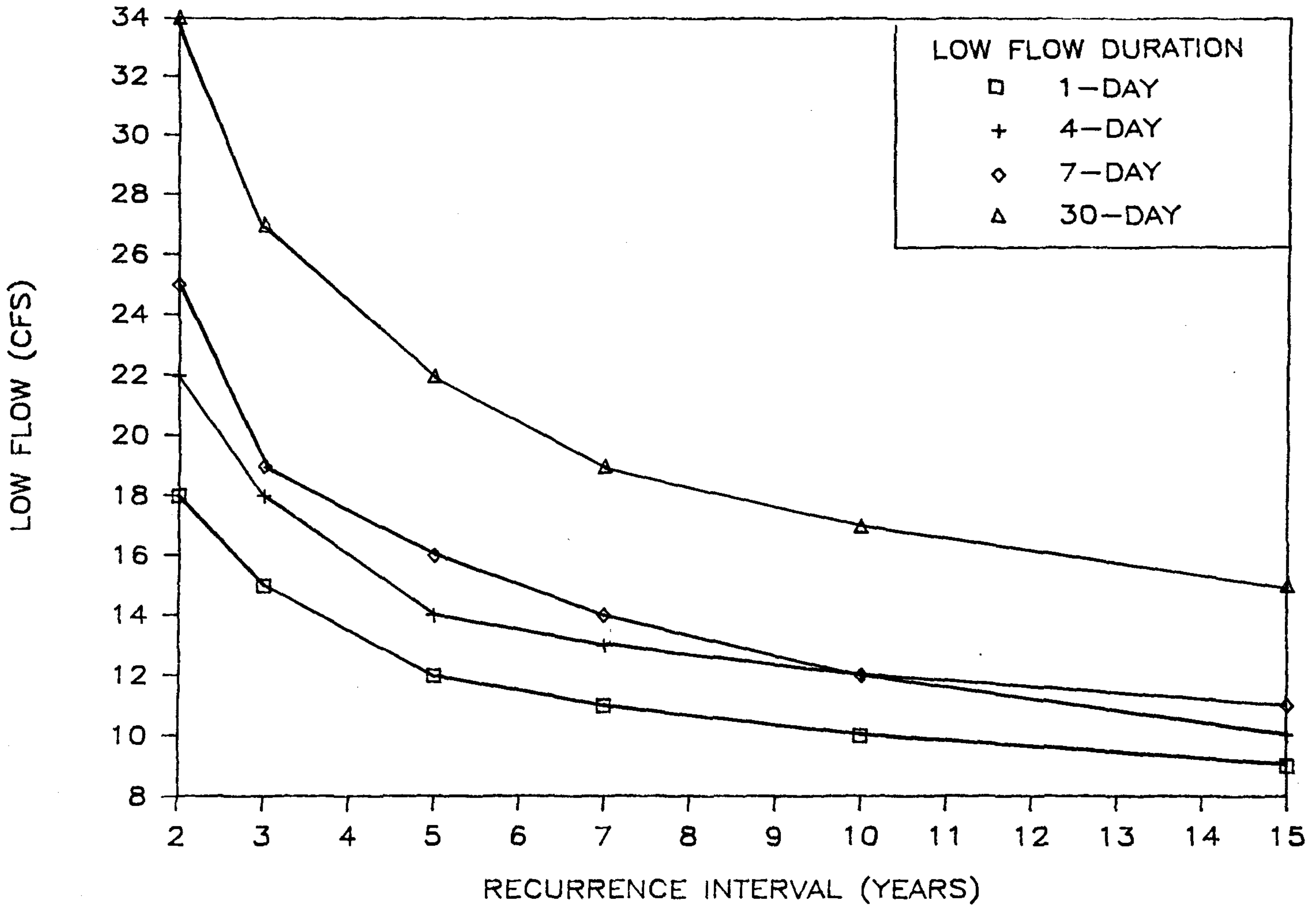

Figure A1.11 Annual frequency curves for 1, 4, 7 and 30-day moving average low flows at Littleton.

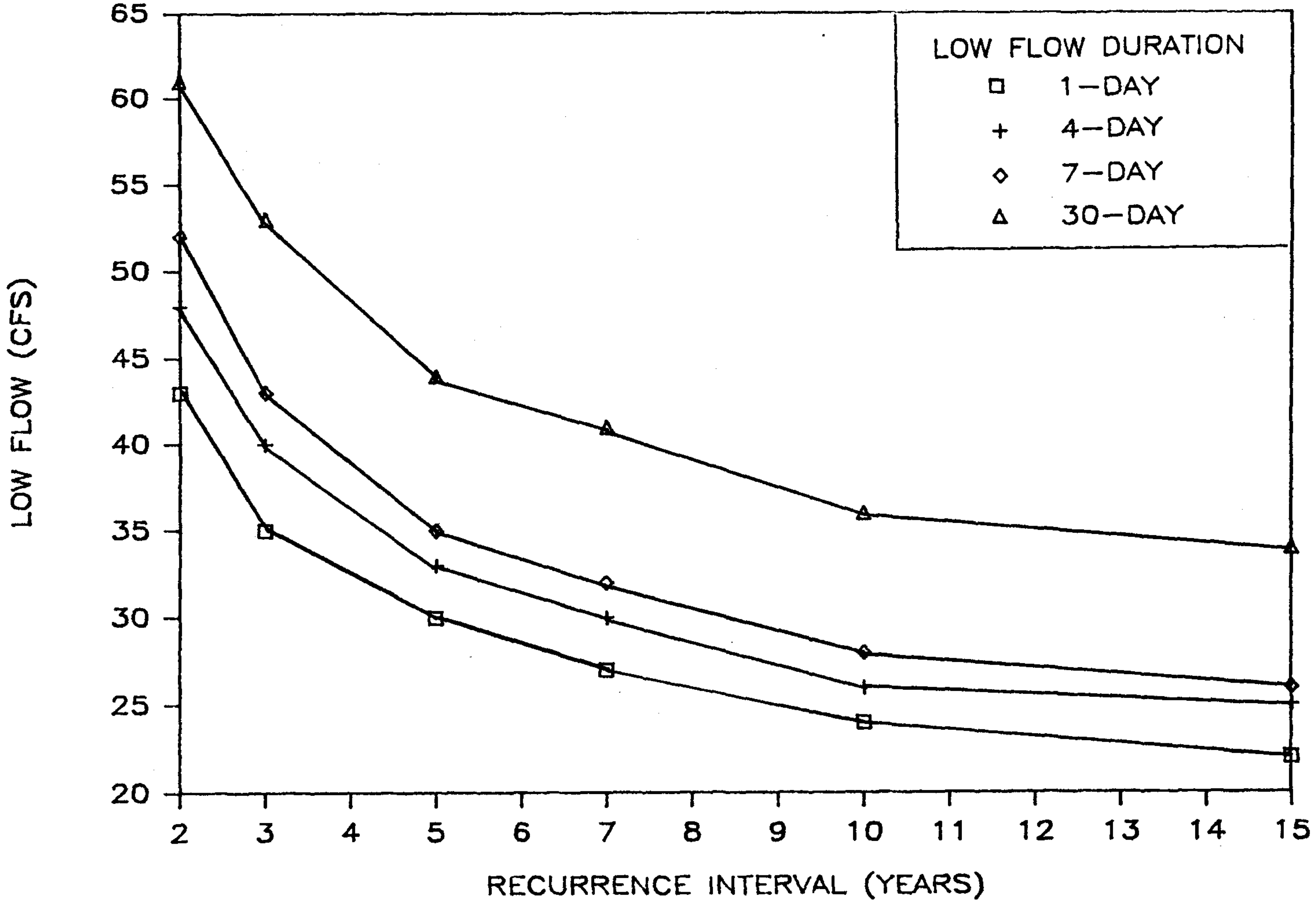

Figure A1.12 Annual frequency curves for 1, 4, 7 and 30-day moving average low flows at Englewood.

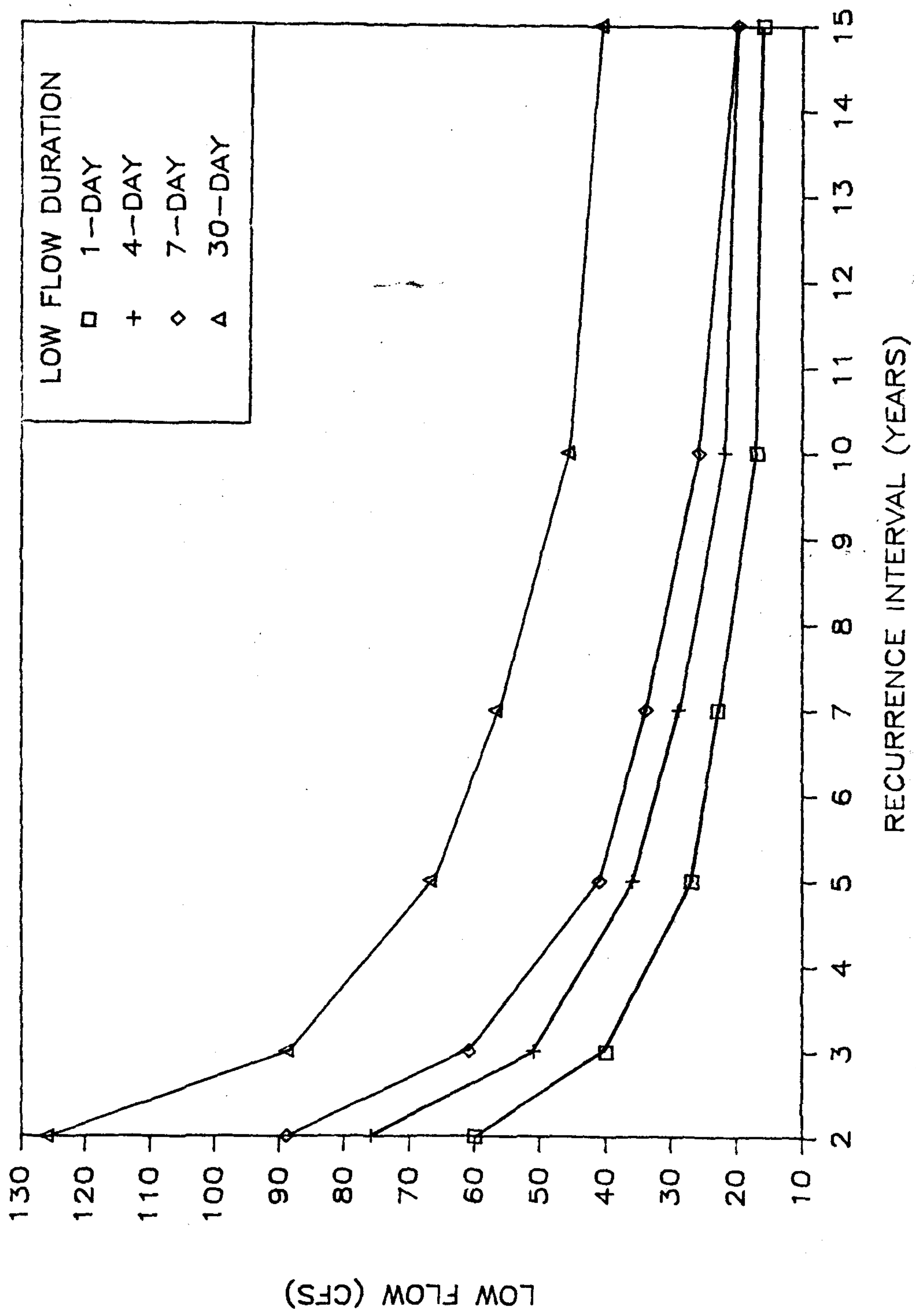

Figure A1.13 Annual frequency curves for 1, 4, 7 and 30-day moving average low flows at Henderson.

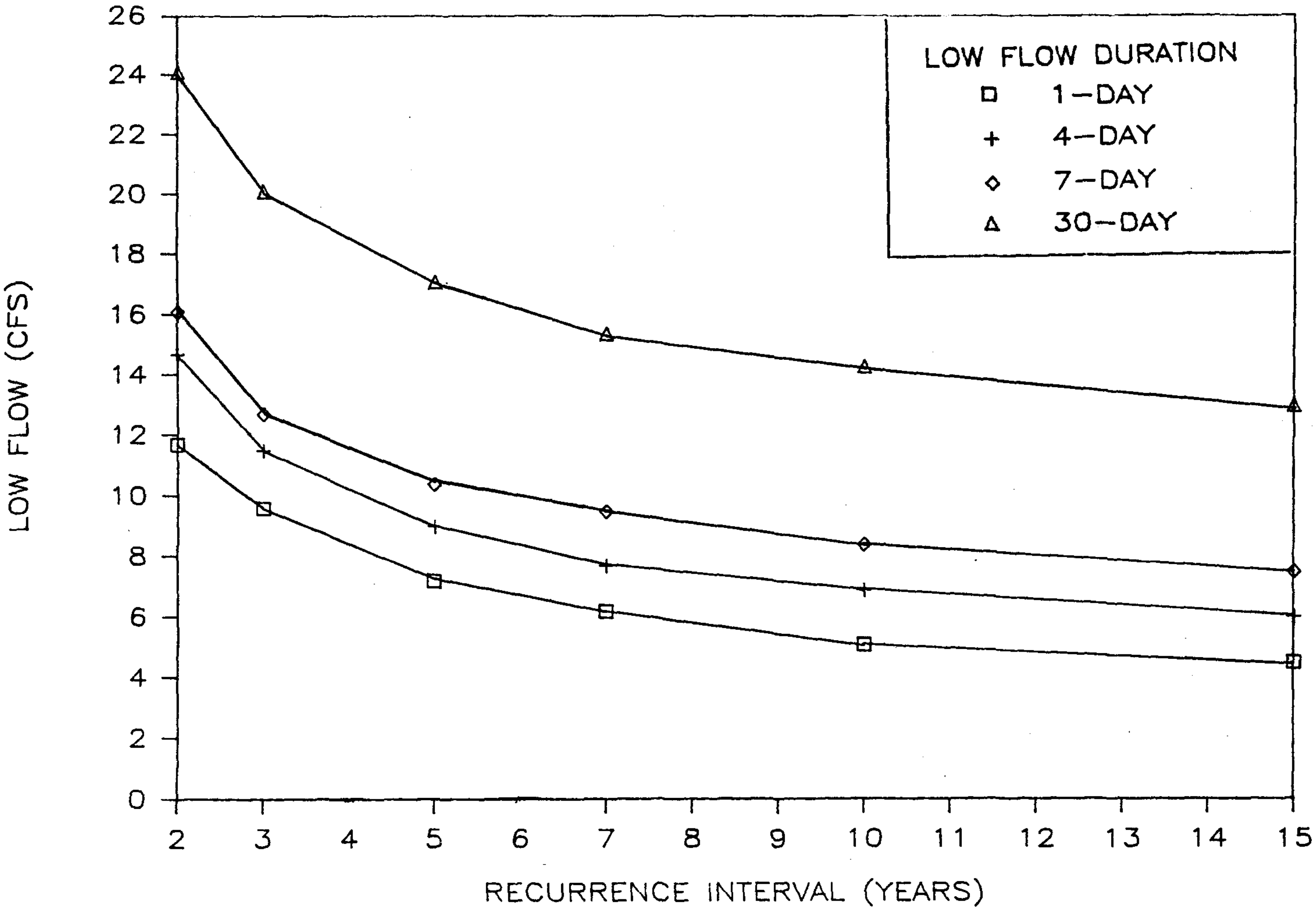

Figure A1.14 Annual frequency curves for 1, 4, 7 and 30-day moving average low flows at Boulder.

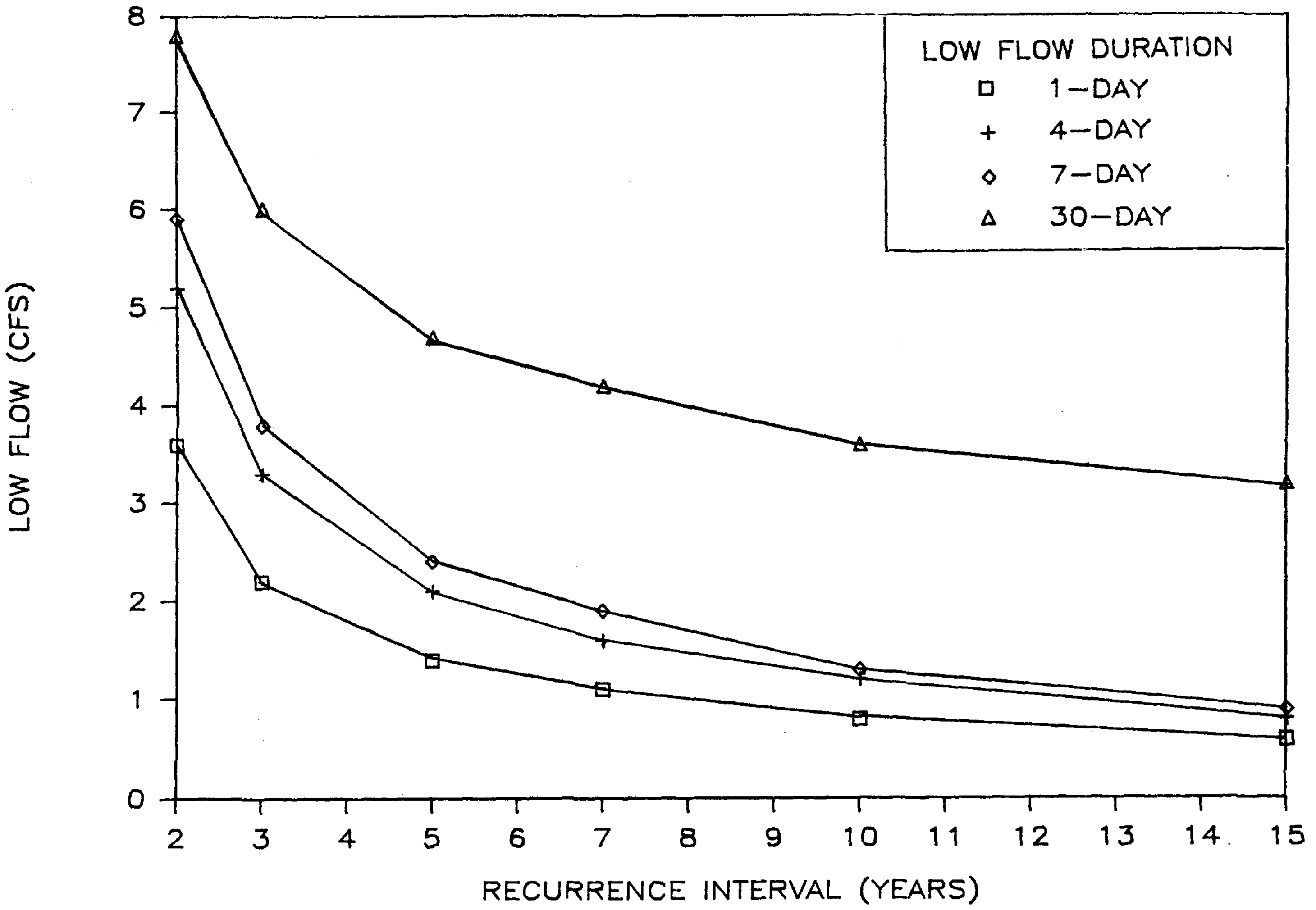

Figure A1.15 Annual frequency curves for 1, 4, 7 and 30-day moving average low flows at Lyons.

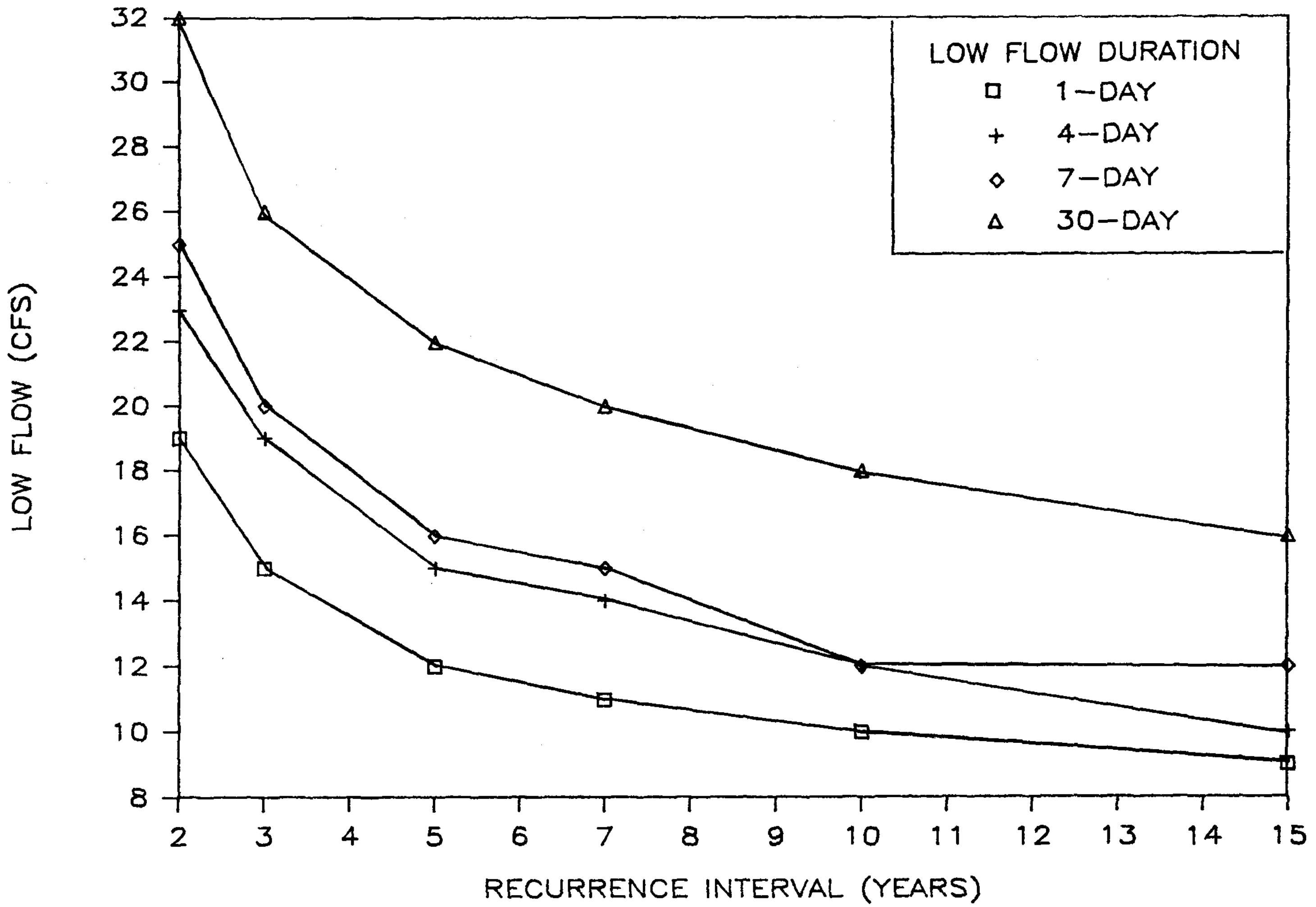

Figure A1.16 Annual frequency curves for 1, 4, 7 and 30-day moving average low flows at Longmont (based on regression of daily flows).

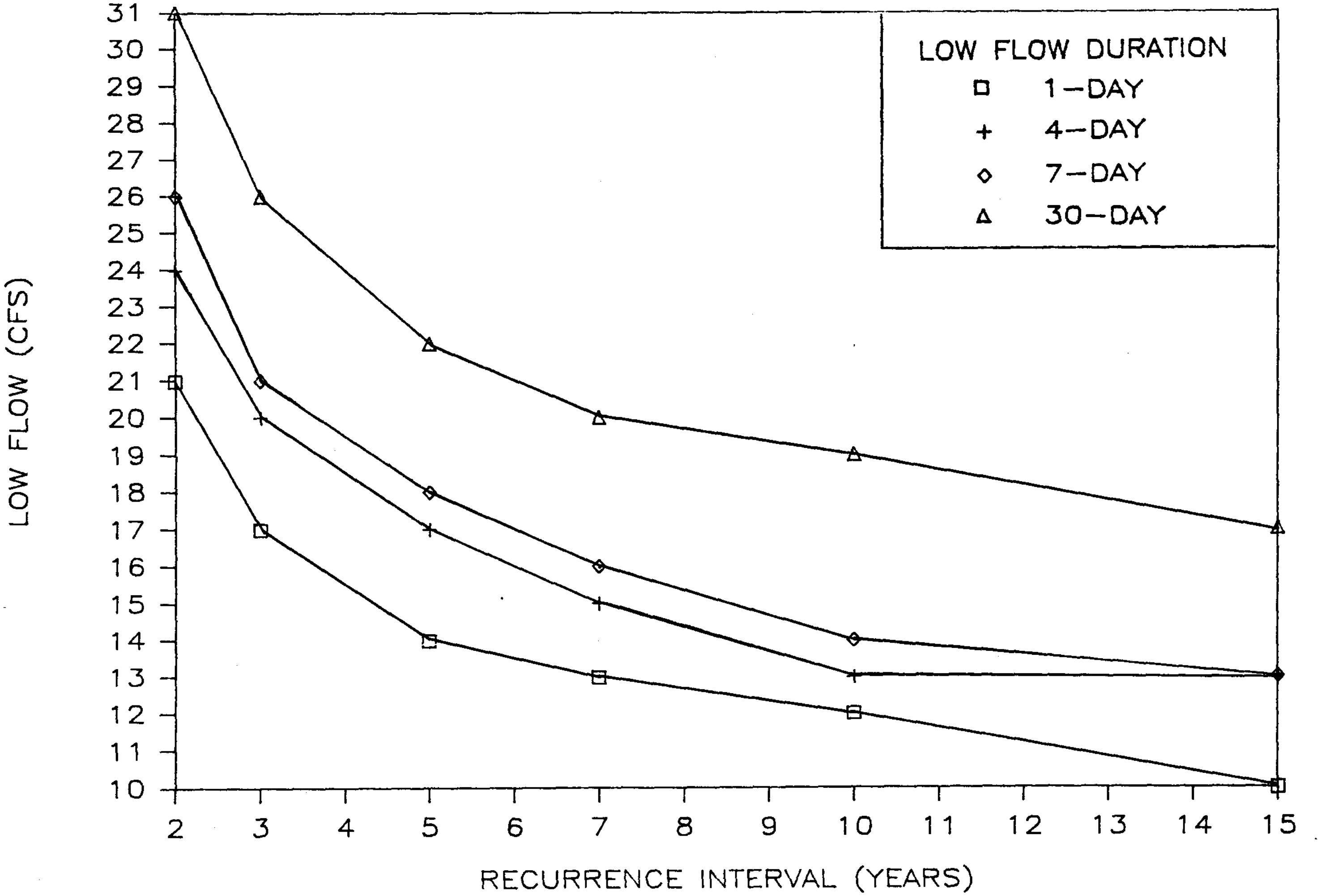

Figure A1.17 Annual frequency curves for 1, 4, 7 and 30-day moving average low flows at Longmont (based on regression of log-transformed daily flows).

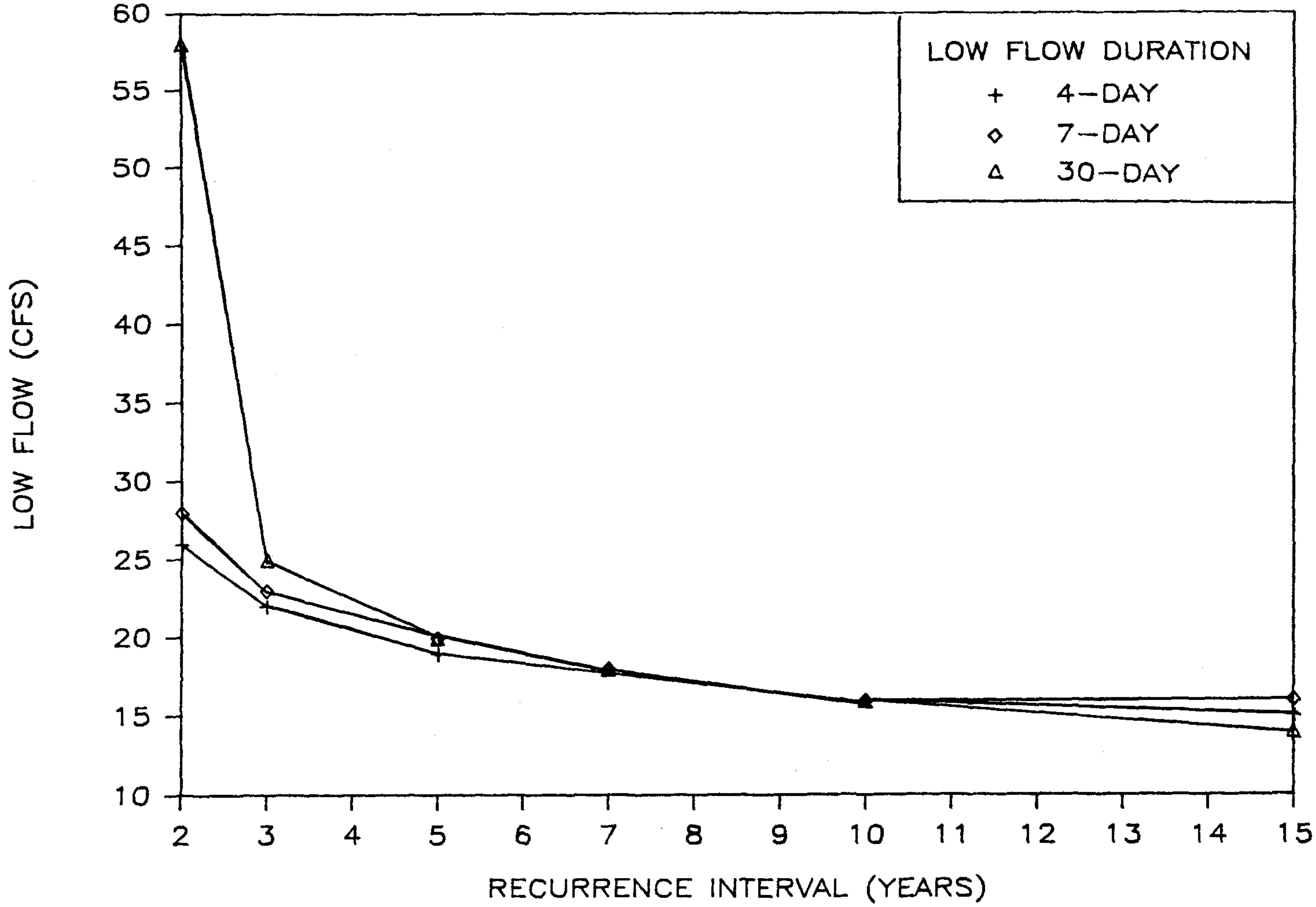

Figure A1.18 Annual frequency curves for 1, 4, 7 and 30-day moving average low flows at Longmont (based on set of regressions of annual flows.

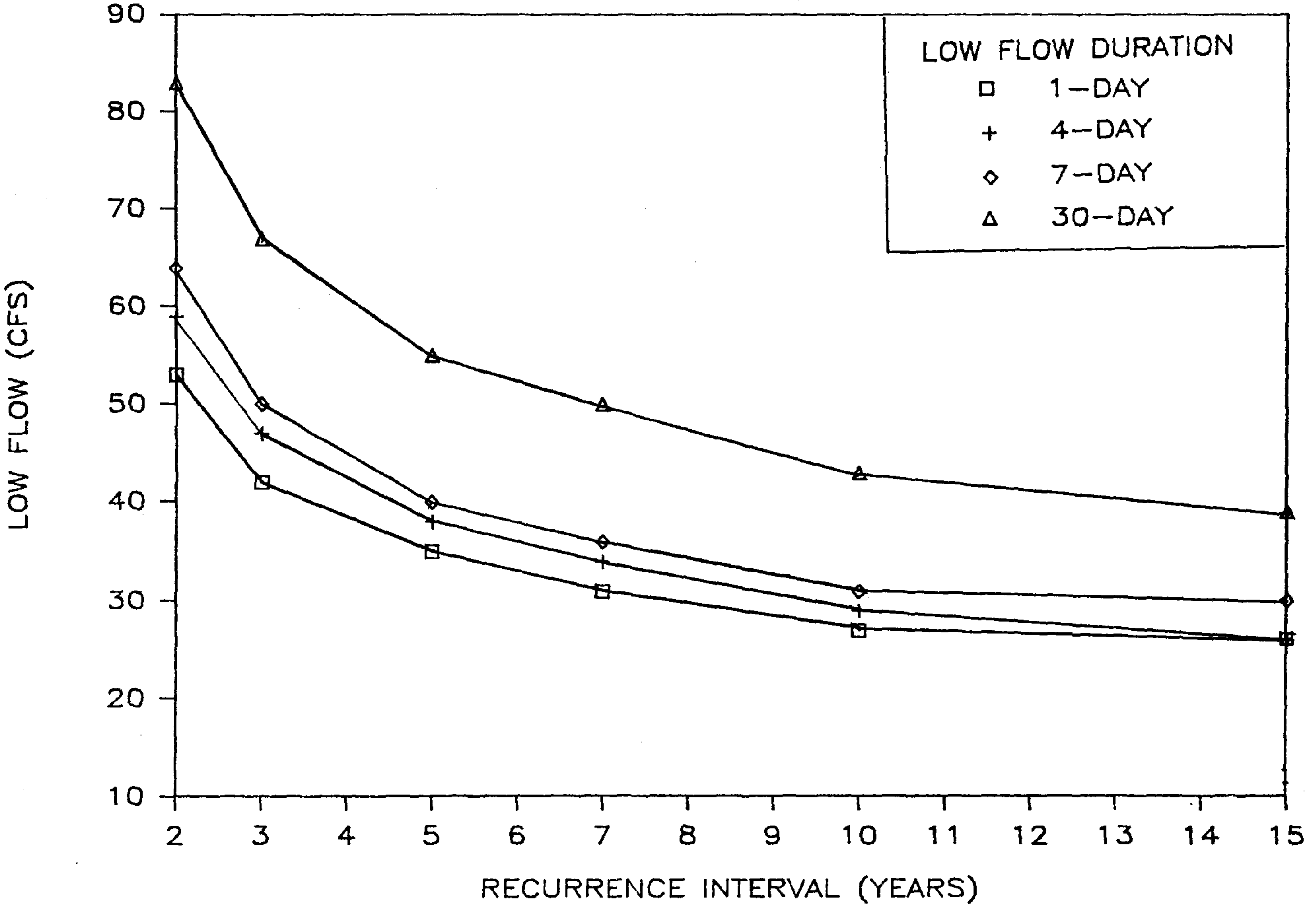

Figure A1.19 Annual frequency curves for 1, 4, 7 and 30-day moving average low flows at Platteville.

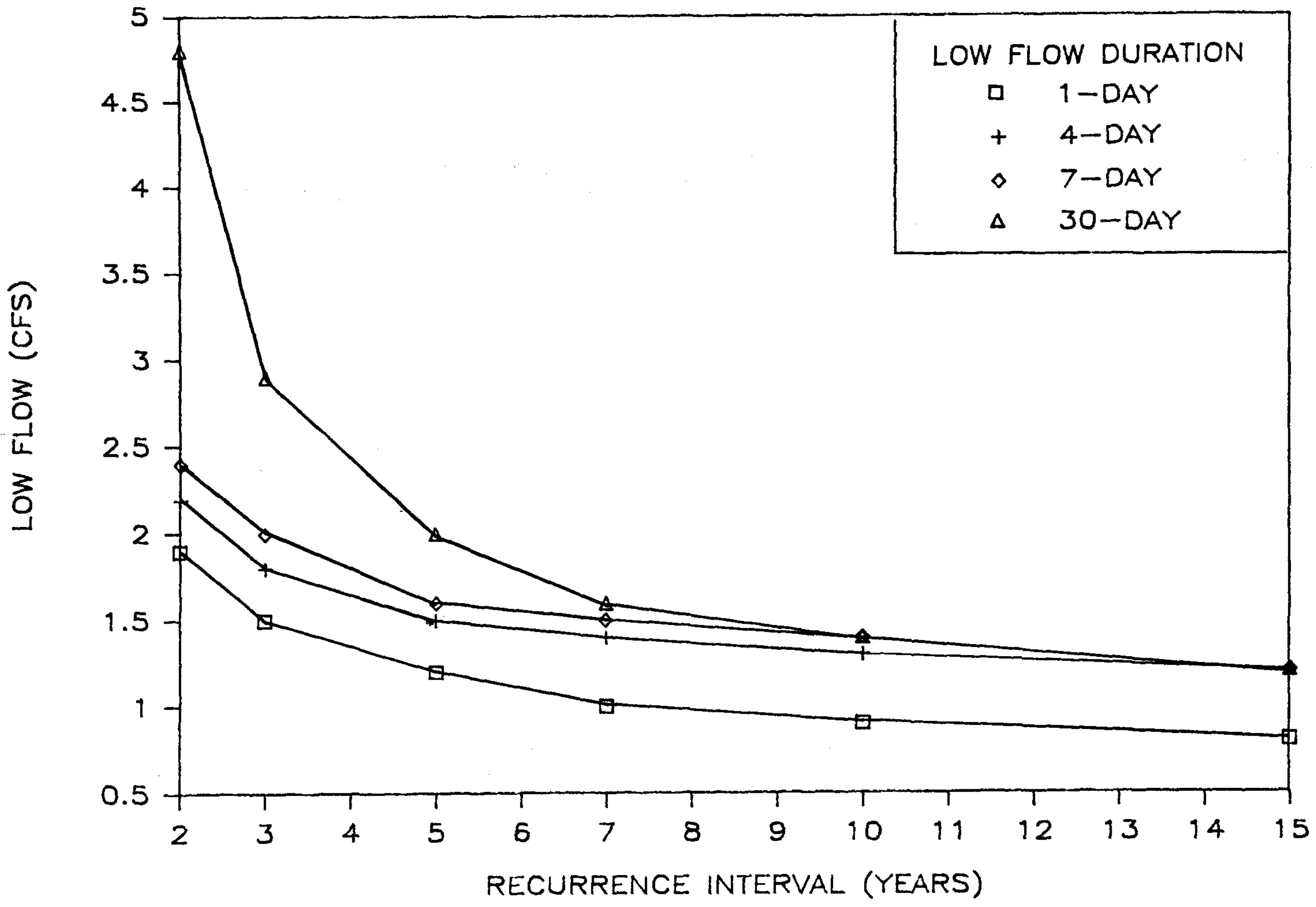

Figure A1.20 Annual frequency curves for 1, 4, 7 and 30-day moving average low flows at Fort Collins.

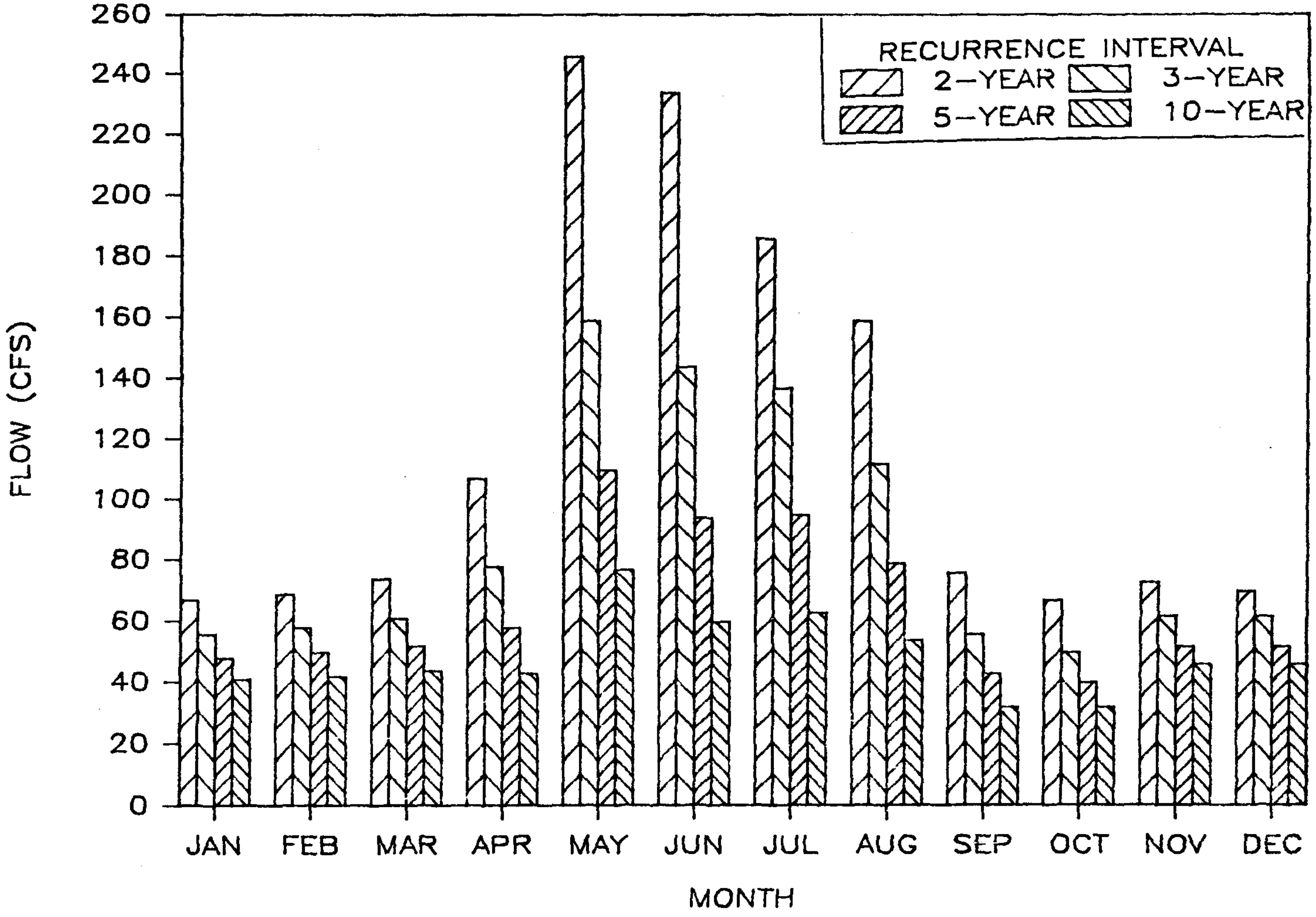

Figure A2.1 Graph of monthly 7-day moving average low flows for 2, 3, 5 and 10 year recurrence intervals at Englewood.

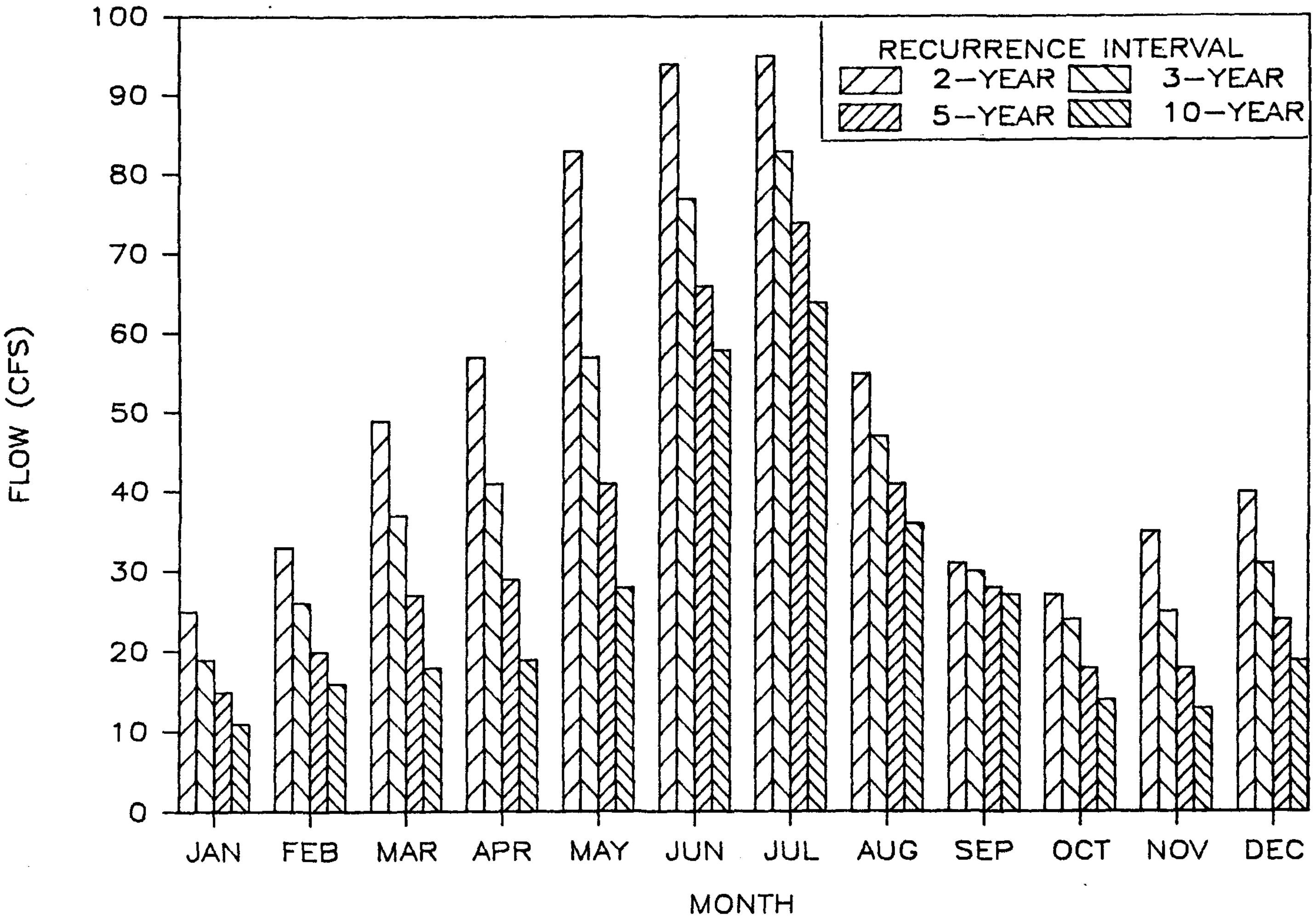

Figure A2.2 Graph of monthly 7-day average low flows for 2, 3, 5 and 10-year recurrence intervals at Boulder.

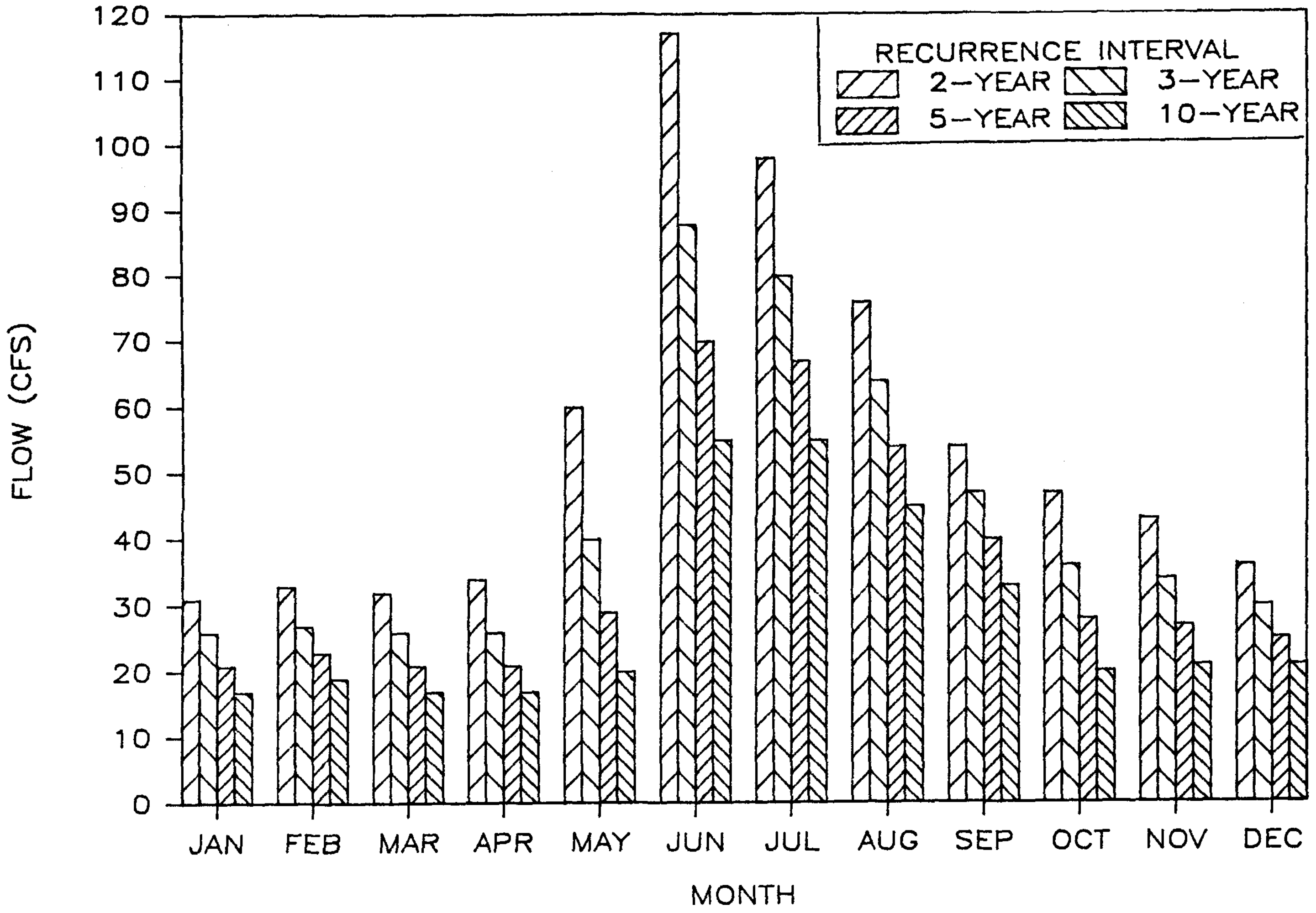

Figure A2.3 Graph of monthly 7-day moving average low flows for 2, 3, 5 and 10-year recurrence intervals at Longmont (based on regression of daily flows).

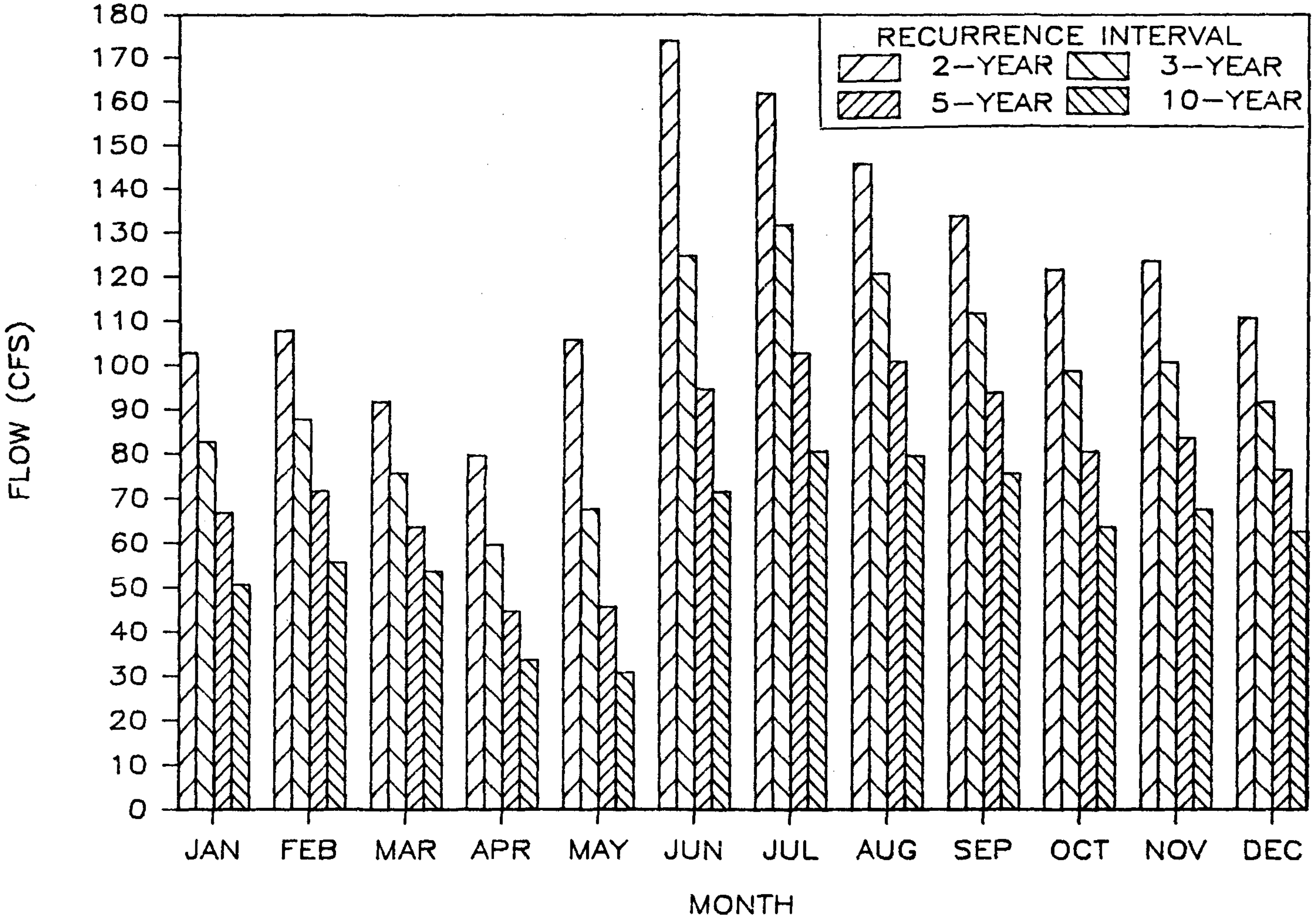

Figure A2.4 Graph of monthly 7-day moving average low flows for 2, 3, 5 and 10 year recurrence intervals at Platteville.

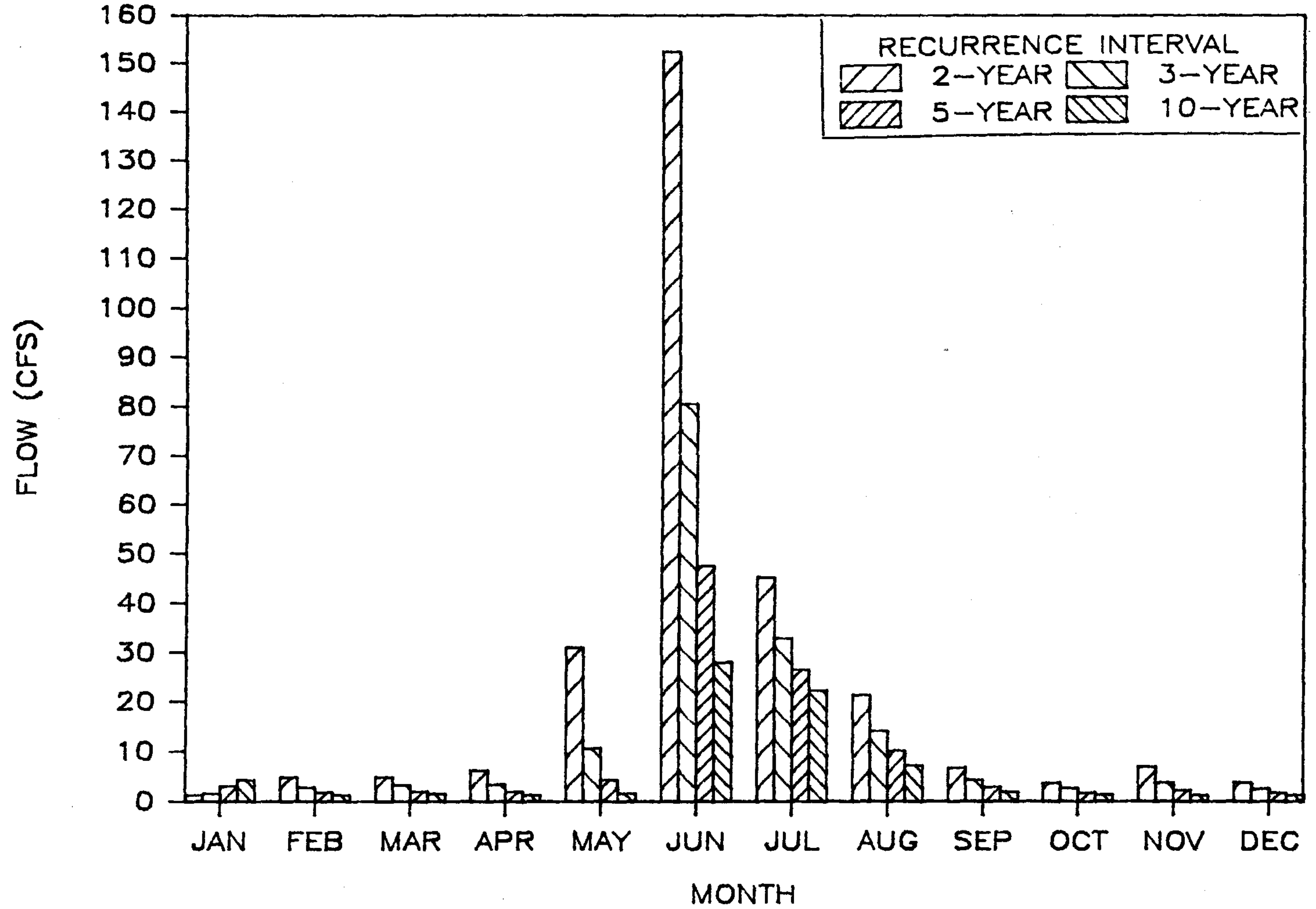

Figure A2.5 Graph of monthly 7-day moving average low flows for 2, 3, 5 and 10 year recurrence intervals at Fort Collins.

APPENDIX B

EFFLUENT LIMIT ANALYSIS

LIST OF TABLES FOR APPENDIX B

LIST OF FIGURES FOR APPENDIX B

Table B1.1. Ammonia effluent limits for the Cities of Littleton and Englewood based on a 7Q10 chronic design flow and an instream ammonia standard of 0.06 mg/l-N.

DISCHARGER: ENGLEWOOD STREAM: SOUTH PLATTE
UPSTREAM FLOW IN CFS: 28.0
UPSTREAM AMMONIA IN mg/l: 0.0
UN-IONIZED AMMONIA STANDARD IN mg/l X 10 0.6
DISCHARGE FLOW IN MGD: 28.0

	pH																									
DEGREES CENTIGRADE	6.5	6.6	6.7	6.8	6.9	7.0	7.1	7.2	7.3	7.4	7.5	7.6	7.7	7.8	7.9	8.0	8.1	8.2	8.3	8.4	8.5	8.6	8.7	8.8	8.9	9.0
3.0	*****	*****	*****	*****	*****	93.5	74.3	59.1	46.9	37.3	29.6	23.6	18.7	14.9	11.9	9.4	7.5	6.0	4.8	3.8	3.1	2.4	2.0	1.6	1.3	1.0
4.0	*****	*****	*****	*****	*****	86.2	68.5	54.4	43.2	34.4	27.3	21.7	17.3	13.7	10.9	8.7	6.9	5.5	4.4	3.5	2.8	2.3	1.8	1.5	1.2	1.0
5.0	*****	*****	*****	*****	*****	79.4	63.1	50.2	39.9	31.7	25.2	20.0	15.9	12.7	10.1	8.0	6.4	5.1	4.1	3.3	2.6	2.1	1.7	1.4	1.1	0.9
6.0	*****	*****	*****	*****	92.2	73.3	58.2	46.3	36.8	29.2	23.2	18.5	14.7	11.7	9.3	7.4	5.9	4.7	3.8	3.0	2.4	1.9	1.6	1.3	1.0	0.8
7.0	*****	*****	*****	*****	85.1	67.6	53.7	42.7	33.9	27.0	21.4	17.1	13.6	10.8	8.6	6.8	5.5	4.4	3.5	2.8	2.2	1.8	1.4	1.2	0.9	0.8
8.0	*****	*****	*****	98.9	78.6	62.4	49.6	39.4	31.3	24.9	19.8	15.8	12.5	10.0	7.9	6.3	5.1	4.0	3.2	2.6	2.1	1.7	1.3	1.1	0.9	0.7
9.0	*****	*****	*****	91.4	72.6	57.7	45.8	36.4	29.0	23.0	18.3	14.6	11.6	9.2	7.3	5.9	4.7	3.7	3.0	2.4	1.9	1.5	1.2	1.0	0.8	0.7
10.0	*****	*****	*****	84.5	67.1	53.3	42.4	33.7	26.8	21.3	16.9	13.5	10.7	8.5	6.8	5.4	4.3	3.5	2.8	2.2	1.8	1.4	1.2	0.9	0.8	0.6
11.0	*****	*****	98.3	78.1	62.1	49.3	39.2	31.2	24.8	19.7	15.7	12.5	9.9	7.9	6.3	5.0	4.0	3.2	2.6	2.1	1.7	1.3	1.1	0.9	0.7	0.6
12.0	*****	*****	91.0	72.3	57.4	45.7	36.3	28.8	22.9	18.2	14.5	11.5	9.2	7.3	5.8	4.7	3.7	3.0	2.4	1.9	1.5	1.2	1.0	0.8	0.7	0.6
13.0	*****	*****	84.2	66.9	53.2	42.3	33.6	26.7	21.2	16.9	13.4	10.7	8.5	6.8	5.4	4.3	3.4	2.8	2.2	1.8	1.4	1.2	0.9	0.8	0.6	0.5
14.0	*****	98.2	78.1	62.0	49.3	39.2	31.1	24.7	19.7	15.7	12.5	9.9	7.9	6.3	5.0	4.0	3.2	2.6	2.1	1.7	1.3	1.1	0.9	0.7	0.6	0.5
15.0	*****	91.1	72.3	57.5	45.7	36.3	28.9	22.9	18.2	14.5	11.5	9.2	7.3	5.8	4.7	3.7	3.0	2.4	1.9	1.5	1.2	1.0	0.8	0.7	0.6	0.5
16.0	*****	84.4	67.1	53.3	42.4	33.7	26.8	21.3	16.9	13.5	10.7	8.5	6.8	5.4	4.3	3.5	2.8	2.2	1.8	1.4	1.2	0.9	0.8	0.6	0.5	0.4
17.0	98.6	78.4	62.3	49.5	39.3	31.3	24.8	19.8	15.7	12.5	10.0	7.9	6.3	5.0	4.0	3.2	2.6	2.1	1.7	1.3	1.1	0.9	0.7	0.6	0.5	0.4
18.0	91.6	72.7	57.8	45.9	36.5	29.0	23.1	18.3	14.6	11.6	9.2	7.4	5.9	4.7	3.7	3.0	2.4	1.9	1.5	1.3	1.0	0.8	0.7	0.6	0.5	0.4
19.0	85.0	67.6	53.7	42.7	33.9	27.0	21.4	17.0	13.6	10.8	8.6	6.8	5.5	4.4	3.5	2.8	2.2	1.8	1.4	1.2	0.9	0.8	0.6	0.5	0.4	0.4
20.0	79.0	62.8	49.9	39.7	31.5	25.1	19.9	15.8	12.6	10.0	8.0	6.4	5.1	4.1	3.2	2.6	2.1	1.7	1.3	1.1	0.9	0.7	0.6	0.5	0.4	0.3
21.0	73.5	58.4	46.4	36.9	29.3	23.3	18.5	14.7	11.7	9.3	7.4	5.9	4.7	3.8	3.0	2.4	1.9	1.6	1.3	1.0	0.8	0.7	0.6	0.5	0.4	0.3
22.0	68.4	54.3	43.2	34.3	27.3	21.7	17.2	13.7	10.9	8.7	6.9	5.5	4.4	3.5	2.8	2.3	1.8	1.5	1.2	1.0	0.8	0.6	0.5	0.4	0.4	0.3
23.0	63.6	50.6	40.2	31.9	25.4	20.2	16.1	12.8	10.2	8.1	6.5	5.1	4.1	3.3	2.6	2.1	1.7	1.4	1.1	0.9	0.7	0.6	0.5	0.4	0.4	0.3
24.0	59.2	47.1	37.4	29.7	23.6	18.8	15.0	11.9	9.5	7.5	6.0	4.8	3.8	3.1	2.5	2.0	1.6	1.3	1.0	0.8	0.7	0.6	0.5	0.4	0.3	0.3
25.0	55.2	43.9	34.9	27.7	22.0	17.5	13.9	11.1	8.8	7.0	5.6	4.5	3.6	2.9	2.3	1.8	1.5	1.2	1.0	0.8	0.6	0.5	0.4	0.4	0.3	0.3

Table B1.2 Ammonia effluent limits for the Cities of Littleton and Englewood based on actual effluent flow, a 7Q10 chronic design flow and an instream ammonia standard of 0.06 mg/l-N.

```
DISCHARGER: ENGLEWOOD               STREAM: SOUTH PLATTE
UPSTREAM FLOW IN CFS:                        28.0
UPSTREAM AMMONIA IN mg/l:                     0.0
UN-IONIZED AMMONIA STANDARD IN mg/l X 10      0.6
DISCHARGE FLOW IN MGD:                       22.0

                                                  pH
           6.5  6.6  6.7  6.8  6.9  7.0  7.1  7.2  7.3  7.4  7.5  7.6  7.7  7.8  7.9  8.0  8.1  8.2  8.3  8.4  8.5  8.6  8.7  8.8  8.9  9.0
DEGREES
CENTIGRADE
  3.0     ******************************82.3 65.4 52.0 41.3 32.8 26.1 20.7 16.5 13.1 10.5  8.3  6.6  5.3  4.2  3.4  2.7  2.2  1.7  1.4  1.1
  4.0     *************************95.4 75.8 60.2 47.9 38.0 30.2 24.0 19.1 15.2 12.1  9.6  7.7  6.1  4.9  3.9  3.1  2.5  2.0  1.6  1.3  1.1
  5.0     *************************87.9 69.9 55.5 44.1 35.1 27.9 22.2 17.6 14.0 11.2  8.9  7.1  5.7  4.5  3.6  2.9  2.3  1.9  1.5  1.2  1.0
  6.0     *************************81.1 64.4 51.2 40.7 32.4 25.7 20.5 16.3 12.9 10.3  8.2  6.5  5.2  4.2  3.3  2.7  2.1  1.7  1.4  1.1  0.9
  7.0     ********************94.2 74.8 59.5 47.3 37.6 29.9 23.7 18.9 15.0 12.0  9.5  7.6  6.0  4.8  3.9  3.1  2.5  2.0  1.6  1.3  1.1  0.9
  8.0     ********************87.0 69.1 54.9 43.6 34.7 27.6 21.9 17.4 13.9 11.0  8.8  7.0  5.6  4.5  3.6  2.9  2.3  1.8  1.5  1.2  1.0  0.8
  9.0     ********************80.4 63.9 50.7 40.3 32.1 25.5 20.3 16.1 12.8 10.2  8.1  6.5  5.2  4.1  3.3  2.6  2.1  1.7  1.4  1.1  0.9  0.7
 10.0     ***************93.5 74.3 59.0 46.9 37.3 29.6 23.6 18.7 14.9 11.9  9.4  7.5  6.0  4.8  3.8  3.1  2.5  2.0  1.6  1.3  1.0  0.9  0.7
 11.0     ***************86.5 68.7 54.6 43.4 34.5 27.4 21.8 17.3 13.8 11.0  8.7  7.0  5.6  4.4  3.5  2.8  2.3  1.8  1.5  1.2  1.0  0.8  0.7
 12.0     ***************80.0 63.6 50.5 40.2 31.9 25.4 20.2 16.1 12.8 10.2  8.1  6.5  5.2  4.1  3.3  2.6  2.1  1.7  1.4  1.1  0.9  0.7  0.6
 13.0     **********93.3 74.1 58.9 46.8 37.2 29.6 23.5 18.7 14.9 11.8  9.4  7.5  6.0  4.8  3.8  3.1  2.4  2.0  1.6  1.3  1.0  0.8  0.7  0.6
 14.0     **********55.4 68.7 54.6 43.4 34.5 27.4 21.8 17.3 13.8 11.0  8.7  7.0  5.6  4.4  3.5  2.8  2.3  1.8  1.5  1.2  1.0  0.8  0.7  0.5
 15.0     **********80.1 63.6 50.6 40.2 32.0 25.4 20.2 16.1 12.8 10.2  8.1  6.5  5.2  4.1  3.3  2.6  2.1  1.7  1.4  1.1  0.9  0.7  0.6  0.5
 16.0     *****93.5 74.3 59.0 46.9 37.3 29.6 23.6 18.7 14.9 11.9  9.4  7.5  6.0  4.8  3.8  3.1  2.5  2.0  1.6  1.3  1.0  0.9  0.7  0.6  0.5
 17.0     *****86.7 68.9 54.8 43.5 34.6 27.5 21.9 17.4 13.8 11.0  8.8  7.0  5.6  4.5  3.6  2.8  2.3  1.8  1.5  1.2  1.0  0.8  0.7  0.5  0.5
 18.0     *****80.5 64.0 50.9 40.4 32.1 25.5 20.3 16.2 12.9 10.2  8.2  6.5  5.2  4.1  3.3  2.7  2.1  1.7  1.4  1.1  0.9  0.7  0.6  0.5  0.4
 19.0      94.1 74.8 59.4 47.2 37.5 29.8 23.7 18.9 15.0 11.9  9.5  7.6  6.0  4.8  3.9  3.1  2.5  2.0  1.6  1.3  1.0  0.9  0.7  0.6  0.5  0.4
 20.0      87.5 69.5 55.2 43.9 34.9 27.7 22.1 17.5 14.0 11.1  8.8  7.1  5.6  4.5  3.6  2.9  2.3  1.9  1.5  1.2  1.0  0.8  0.7  0.5  0.5  0.4
 21.0      81.3 64.6 51.4 40.8 32.5 25.8 20.5 16.3 13.0 10.3  8.2  6.6  5.2  4.2  3.3  2.7  2.1  1.7  1.4  1.1  0.9  0.8  0.6  0.5  0.4  0.4
 22.0      75.7 60.1 47.8 38.0 30.2 24.0 19.1 15.2 12.1  9.6  7.7  6.1  4.9  3.9  3.1  2.5  2.0  1.6  1.3  1.1  0.9  0.7  0.6  0.5  0.4  0.3
 23.0      70.4 56.0 44.5 35.4 28.1 22.3 17.8 14.1 11.3  9.0  7.1  5.7  4.5  3.6  2.9  2.3  1.9  1.5  1.2  1.0  0.8  0.7  0.6  0.5  0.4  0.3
 24.0      65.6 52.1 41.4 32.9 26.2 20.8 16.6 13.2 10.5  8.4  6.7  5.3  4.2  3.4  2.7  2.2  1.8  1.4  1.1  0.9  0.8  0.6  0.5  0.4  0.4  0.3
 25.0      61.1 48.6 38.6 30.7 24.4 19.4 15.4 12.3  9.8  7.8  6.2  5.0  4.0  3.2  2.5  2.0  1.6  1.3  1.1  0.9  0.7  0.6  0.5  0.4  0.4  0.3
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Table B1.3 Ammonia effluent limits for the Cities of Littleton and Englewood based on a chronic design flow of 30Q10 and an instream ammonia standard of 0.06 mg/l-N.

DISCHARGER: ENGLEWOOD STREAM: SOUTH PLATTE
UPSTREAM FLOW IN CFS: 36.0
UPSTREAM AMMONIA IN mg/l: 0.0
UN-IONIZED AMMONIA STANDARD IN mg/l X 10 0.6
DISCHARGE FLOW IN MGD: 28.0

												pH														
DEGREES CENTIGRADE	6.5	6.6	6.7	6.8	6.9	7.0	7.1	7.2	7.3	7.4	7.5	7.6	7.7	7.8	7.9	8.0	8.1	8.2	8.3	8.4	8.5	8.6	8.7	8.8	8.9	9.0
3.0	*****	*****	*****	*****	*****	*****	82.7	65.7	52.2	41.5	33.0	26.2	20.8	16.6	13.2	10.5	8.4	6.7	5.3	4.2	3.4	2.7	2.2	1.8	1.4	1.1
4.0	*****	*****	*****	*****	*****	95.8	76.1	60.5	48.1	38.2	30.4	24.2	19.2	15.3	12.2	9.7	7.7	6.1	4.9	3.9	3.1	2.5	2.0	1.6	1.3	1.1
5.0	*****	*****	*****	*****	*****	88.3	70.2	55.8	44.3	35.2	28.0	22.3	17.7	14.1	11.2	8.9	7.1	5.7	4.5	3.6	2.9	2.3	1.9	1.5	1.2	1.0
6.0	*****	*****	*****	*****	*****	81.5	64.7	51.4	40.9	32.5	25.8	20.5	16.3	13.0	10.4	8.2	6.6	5.2	4.2	3.3	2.7	2.2	1.7	1.4	1.1	0.9
7.0	*****	*****	*****	*****	94.6	75.2	59.8	47.5	37.7	30.0	23.9	19.0	15.1	12.0	9.6	7.6	6.1	4.8	3.9	3.1	2.5	2.0	1.6	1.3	1.1	0.9
8.0	*****	*****	*****	*****	87.4	69.4	55.2	43.9	34.9	27.7	22.0	17.5	13.9	11.1	8.8	7.0	5.6	4.5	3.6	2.9	2.3	1.9	1.5	1.2	1.0	0.8
9.0	*****	*****	*****	*****	80.7	64.2	51.0	40.5	32.2	25.6	20.4	16.2	12.9	10.3	8.2	6.5	5.2	4.2	3.3	2.7	2.1	1.7	1.4	1.1	0.9	0.8
10.0	*****	*****	*****	93.9	74.6	59.3	47.1	37.5	29.8	23.7	18.8	15.0	11.9	9.5	7.6	6.0	4.8	3.8	3.1	2.5	2.0	1.6	1.3	1.0	0.9	0.7
11.0	*****	*****	*****	86.9	69.0	54.9	43.6	34.7	27.5	21.9	17.4	13.9	11.0	8.8	7.0	5.6	4.5	3.6	2.9	2.3	1.8	1.5	1.2	1.0	0.8	0.7
12.0	*****	*****	*****	80.4	63.9	50.8	40.4	32.1	25.5	20.3	16.1	12.8	10.2	8.1	6.5	5.2	4.1	3.3	2.6	2.1	1.7	1.4	1.1	0.9	0.7	0.6
13.0	*****	*****	93.7	74.5	59.2	47.0	37.4	29.7	23.6	18.8	14.9	11.9	9.5	7.5	6.0	4.8	3.8	3.1	2.5	2.0	1.6	1.3	1.0	0.9	0.7	0.6
14.0	*****	*****	86.8	69.0	54.8	43.6	34.6	27.5	21.9	17.4	13.9	11.0	8.8	7.0	5.6	4.5	3.6	2.9	2.3	1.8	1.5	1.2	1.0	0.8	0.7	0.5
15.0	*****	*****	80.5	63.9	50.8	40.4	32.1	25.5	20.3	16.1	12.8	10.2	8.1	6.5	5.2	4.1	3.3	2.7	2.1	1.7	1.4	1.1	0.9	0.7	0.6	0.5
16.0	*****	93.9	74.6	59.3	47.1	37.5	29.8	23.7	18.8	15.0	11.9	9.5	7.6	6.0	4.8	3.8	3.1	2.5	2.0	1.6	1.3	1.0	0.9	0.7	0.6	0.5
17.0	*****	87.1	69.2	55.0	43.7	34.8	27.6	22.0	17.5	13.9	11.1	8.8	7.0	5.6	4.5	3.6	2.9	2.3	1.8	1.5	1.2	1.0	0.8	0.7	0.5	0.5
18.0	*****	80.9	64.3	51.1	40.6	32.3	25.7	20.4	16.2	12.9	10.3	8.2	6.5	5.2	4.2	3.3	2.7	2.1	1.7	1.4	1.1	0.9	0.8	0.6	0.5	0.4
19.0	94.6	75.1	59.7	47.5	37.7	30.0	23.8	19.0	15.1	12.0	9.6	7.6	6.1	4.8	3.9	3.1	2.5	2.0	1.6	1.3	1.1	0.9	0.7	0.6	0.5	0.4
20.0	87.9	69.8	55.5	44.1	35.1	27.9	22.2	17.6	14.0	11.2	8.9	7.1	5.6	4.5	3.6	2.9	2.3	1.9	1.5	1.2	1.0	0.8	0.7	0.5	0.5	0.4
21.0	81.7	64.9	51.6	41.0	32.6	25.9	20.6	16.4	13.0	10.4	8.3	6.6	5.3	4.2	3.4	2.7	2.2	1.7	1.4	1.1	0.9	0.8	0.6	0.5	0.4	0.4
22.0	76.0	60.4	48.0	38.2	30.3	24.1	19.2	15.3	12.1	9.7	7.7	6.1	4.9	3.9	3.1	2.5	2.0	1.6	1.3	1.1	0.9	0.7	0.6	0.5	0.4	0.3
23.0	70.8	56.2	44.7	35.5	28.2	22.4	17.9	14.2	11.3	9.0	7.2	5.7	4.6	3.7	2.9	2.3	1.9	1.5	1.2	1.0	0.8	0.7	0.6	0.5	0.4	0.3
24.0	65.9	52.4	41.6	33.1	26.3	20.9	16.6	13.2	10.5	8.4	6.7	5.3	4.3	3.4	2.7	2.2	1.8	1.4	1.2	0.9	0.8	0.6	0.5	0.4	0.4	0.3
25.0	61.4	48.8	38.8	30.8	24.5	19.5	15.5	12.3	9.8	7.8	6.2	5.0	4.0	3.2	2.5	2.0	1.6	1.3	1.1	0.9	0.7	0.6	0.5	0.4	0.4	0.3

Table B1.4 Ammonia effluent limits for the Cities of Littleton and Englewood based on a 30Q3 chronič design flow and an instream ammonia standard of 0.06 mg/l-N.

```
DISCHARGER: ENGLEWOOD            STREAM: SOUTH PLATTE
UPSTREAM FLOW IN CFS:                   53.0
UPSTREAM AMMONIA IN mg/l:                0.0
UN-IONIZED AMMONIA STANDARD IN mg/l X 10 0.6
DISCHARGE FLOW IN MGD:                  28.0

                                                                 pH
          6.5  6.6  6.7  6.8  6.9  7.0  7.1  7.2  7.3  7.4  7.5  7.6  7.7  7.8  7.9  8.0  8.1  8.2  8.3  8.4  8.5  8.6  8.7  8.8  8.9  9.0
DEGREES
CENTIGRADE
  3.0    ***********************************79.8 63.4 50.4 40.0 31.8 25.3 20.1 16.0 12.8 10.2  6.1  6.5  5.2  4.1  3.3  2.7  2.1  1.7  1.4
  4.0    ******************************92.5 73.5 58.4 46.4 36.9 29.3 23.3 18.6 14.8 11.8  9.4  7.5  6.0  4.8  3.8  3.1  2.5  2.0  1.6  1.3
  5.0    ******************************85.2 67.7 53.8 42.8 34.0 27.0 21.5 17.1 13.6 10.8  8.6  6.9  5.5  4.4  3.5  2.8  2.3  1.8  1.5  1.2
  6.0    *************************58.9 78.6 62.5 49.7 39.5 31.4 25.0 19.8 15.8 12.6 10.0  8.0  6.4  5.1  4.1  3.3  2.6  2.1  1.7  1.4  1.1
  7.0    *************************91.3 72.6 57.7 45.8 36.4 29.0 23.0 18.3 14.6 11.6  9.3  7.4  5.9  4.7  3.8  3.0  2.4  2.0  1.6  1.3  1.0
  8.0    *************************84.3 67.0 53.2 42.3 33.6 26.8 21.3 16.9 13.5 10.7  8.6  6.8  5.4  4.4  3.5  2.8  2.2  1.8  1.5  1.2  1.0
  9.0    ********************98.0 77.9 61.9 49.2 39.1 31.1 24.7 19.7 15.7 12.5  9.9  7.9  6.3  5.0  4.0  3.2  2.6  2.1  1.7  1.4  1.1  0.9
 10.0    ********************90.6 72.0 57.2 45.5 36.2 28.8 22.9 18.2 14.5 11.5  9.2  7.3  5.8  4.7  3.7  3.0  2.4  1.9  1.6  1.3  1.0  0.9
 11.0    ********************83.8 66.6 52.9 42.1 33.5 26.6 21.2 16.8 13.4 10.7  6.5  6.8  5.4  4.3  3.5  2.8  2.2  1.8  1.5  1.2  1.0  0.8
 12.0    ***************97.6 77.6 61.7 49.0 39.0 31.0 24.6 19.6 15.6 12.4  9.9  7.9  6.3  5.0  4.0  3.2  2.6  2.1  1.7  1.4  1.1  0.9  0.7
 13.0    ***************90.4 71.8 57.1 45.4 36.1 28.7 22.8 18.1 14.4 11.5  9.2  7.3  5.8  4.7  3.7  3.0  2.4  1.9  1.6  1.3  1.0  0.9  0.7
 14.0    ***************83.8 66.6 52.9 42.0 33.4 26.6 21.1 16.8 13.4 10.7  8.5  6.8  5.4  4.3  3.5  2.8  2.2  1.8  1.5  1.2  1.0  0.8  0.7
 15.0    **********97.7 77.6 61.7 49.0 39.0 31.0 24.6 19.6 15.6 12.4  9.9  7.9  6.3  5.0  4.0  3.2  2.6  2.1  1.7  1.4  1.1  0.9  0.7  0.6
 16.0    **********90.6 72.0 57.2 45.5 36.2 28.7 22.9 18.2 14.5 11.5  9.2  7.3  5.8  4.7  3.7  3.0  2.4  1.9  1.6  1.3  1.0  0.9  0.7  0.6
 17.0    **********84.1 66.8 53.1 42.2 33.6 26.7 21.2 16.9 13.4 10.7  8.5  6.8  5.4  4.3  3.5  2.8  2.2  1.8  1.5  1.2  1.0  0.8  0.7  0.6
 18.0    *****98.2 78.1 62.0 49.3 39.2 31.2 24.8 19.7 15.7 12.5  9.9  7.9  6.3  5.1  4.0  3.2  2.6  2.1  1.7  1.4  1.1  0.9  0.8  0.6  0.5
 19.0    *****91.3 72.5 57.6 45.8 36.4 28.9 23.0 18.3 14.6 11.6  9.2  7.4  5.9  4.7  3.8  3.0  2.4  2.0  1.6  1.3  1.0  0.9  0.7  0.6  0.5
 20.0    *****84.8 67.4 53.6 42.6 33.8 26.9 21.4 17.0 13.6 10.8  8.6  6.9  5.5  4.4  3.5  2.8  2.3  1.8  1.5  1.2  1.0  0.8  0.7  0.6  0.5
 21.0    99.2 78.9 62.7 49.8 39.6 31.5 25.0 19.9 15.8 12.6 10.0  8.0  6.4  5.1  4.1  3.3  2.6  2.1  1.7  1.4  1.1  0.9  0.8  0.6  0.5  0.4
 22.0    92.3 73.4 58.3 46.3 36.8 29.3 23.3 18.5 14.7 11.7  9.4  7.5  5.9  4.8  3.8  3.0  2.4  2.0  1.6  1.3  1.1  0.9  0.7  0.6  0.5  0.4
 23.0    85.9 68.3 54.3 43.1 34.3 27.3 21.7 17.3 13.7 10.9  8.7  6.9  5.5  4.4  3.5  2.8  2.3  1.8  1.5  1.2  1.0  0.8  0.7  0.6  0.5  0.4
 24.0    80.0 63.6 50.5 40.2 31.9 25.4 20.2 16.1 12.8 10.2  8.1  6.5  5.2  4.1  3.3  2.7  2.1  1.7  1.4  1.1  0.9  0.8  0.6  0.5  0.5  0.4
 25.0    74.5 59.2 47.1 37.4 29.8 23.7 18.8 15.0 11.9  9.5  7.6  6.0  4.8  3.9  3.1  2.5  2.0  1.6  1.3  1.1  0.9  0.7  0.6  0.5  0.4  0.4
```

Table B1.5 Ammonia effluent limits for the Cities of Littleton and Englewood based on a 7Q10 chronic design flow and an instream ammonia standard of 0.10 mg/l-N.

```
DISCHARGER: ENGLEWOOD          STREAM: SOUTH PLATTE
UPSTREAM FLOW IN CFS:                     28.0
UPSTREAM AMMONIA IN mg/l:                  0.0
UN-IONIZED AMMONIA STANDARD IN mg/l X 10   1.0
DISCHARGE FLOW IN MGD:                    28.0

                                                               pH
           6.5  6.6  6.7  6.8  6.9  7.0  7.1  7.2  7.3  7.4  7.5  7.6  7.7  7.8  7.9  8.0  8.1  8.2  8.3  8.4  8.5  8.6  8.7  8.8  8.9  9.0
DEGREES
CENTIGRADE
  3.0     ************************************98.4 78.2 62.2 49.4 39.3 31.2 24.8 19.8 15.7 12.5 10.0  8.0  6.4  5.1  4.1  3.3  2.6  2.1  1.7
  4.0     ************************************90.7 72.1 57.3 45.5 36.2 28.8 22.9 18.2 14.5 11.6  9.2  7.4  5.9  4.7  3.8  3.0  2.4  2.0  1.6
  5.0     ************************************83.6 66.4 52.8 42.0 33.4 26.5 21.1 16.8 13.4 10.7  8.5  6.8  5.4  4.3  3.5  2.8  2.3  1.8  1.5
  6.0     *******************************97.0 77.1 61.3 48.7 38.7 30.8 24.5 19.5 15.5 12.4  9.9  7.9  6.3  5.0  4.0  3.2  2.6  2.1  1.7  1.4
  7.0     *******************************89.5 71.2 56.6 45.0 35.7 28.4 22.6 18.0 14.3 11.4  9.1  7.3  5.8  4.6  3.7  3.0  2.4  1.9  1.6  1.3
  8.0     *******************************82.7 65.7 52.2 41.5 33.0 26.3 20.9 16.6 13.2 10.6  8.4  6.7  5.4  4.3  3.4  2.8  2.2  1.8  1.5  1.2
  9.0     **************************96.1 76.4 60.7 48.3 38.4 30.5 24.3 19.3 15.4 12.2  9.8  7.8  6.2  5.0  4.0  3.2  2.6  2.1  1.7  1.4  1.1
 10.0     **************************88.9 70.6 56.1 44.6 35.5 28.2 22.4 17.9 14.2 11.3  9.0  7.2  5.8  4.6  3.7  3.0  2.4  1.9  1.6  1.3  1.1
 11.0     **************************82.2 65.3 51.9 41.3 32.8 26.1 20.8 16.5 13.2 10.5  8.4  6.7  5.3  4.3  3.4  2.8  2.2  1.8  1.5  1.2  1.0
 12.0     *********************95.7 76.1 60.5 48.1 38.2 30.4 24.2 19.2 15.3 12.2  9.7  7.8  6.2  5.0  4.0  3.2  2.6  2.1  1.7  1.4  1.1  0.9
 13.0     *********************88.7 70.5 56.0 44.5 35.4 28.1 22.4 17.8 14.2 11.3  9.0  7.2  5.7  4.6  3.7  3.0  2.4  1.9  1.6  1.3  1.0  0.9
 14.0     *********************82.1 65.3 51.9 41.2 32.8 26.1 20.8 16.5 13.2 10.5  8.4  6.7  5.3  4.3  3.4  2.8  2.2  1.8  1.5  1.2  1.0  0.8
 15.0     ****************95.8 76.1 60.5 48.1 38.2 30.4 24.2 19.2 15.3 12.2  9.7  7.8  6.2  5.0  4.0  3.2  2.6  2.1  1.7  1.4  1.1  0.9  0.8
 16.0     ****************88.9 70.6 56.1 44.6 35.5 28.2 22.4 17.9 14.2 11.3  9.0  7.2  5.8  4.6  3.7  3.0  2.4  1.9  1.6  1.3  1.1  0.9  0.7
 17.0     ****************82.5 65.5 52.1 41.4 32.9 26.2 20.8 16.6 13.2 10.5  8.4  6.7  5.4  4.3  3.4  2.8  2.2  1.8  1.5  1.2  1.0  0.8  0.7
 18.0     ***********96.3 76.6 60.8 48.4 38.5 30.6 24.3 19.4 15.4 12.3  9.8  7.8  6.2  5.0  4.0  3.2  2.6  2.1  1.7  1.4  1.1  0.9  0.8  0.6
 19.0     ***********89.5 71.1 56.5 44.9 35.7 28.4 22.6 18.0 14.3 11.4  9.1  7.3  5.8  4.6  3.7  3.0  2.4  1.9  1.6  1.3  1.1  0.9  0.7  0.6
 20.0     ***********83.2 66.1 52.5 41.8 33.2 26.4 21.0 16.7 13.3 10.6  8.5  6.8  5.4  4.3  3.5  2.8  2.2  1.8  1.5  1.2  1.0  0.8  0.7  0.6
 21.0     ******97.3 77.3 61.5 48.9 38.8 30.9 24.6 19.5 15.6 12.4  9.9  7.9  6.3  5.0  4.0  3.2  2.6  2.1  1.7  1.4  1.1  0.9  0.8  0.7  0.6
 22.0     ******90.5 71.9 57.2 45.5 36.1 28.7 22.9 18.2 14.5 11.5  9.2  7.3  5.9  4.7  3.8  3.0  2.4  2.0  1.6  1.3  1.1  0.9  0.7  0.6  0.5
 23.0     ******84.3 67.0 53.2 42.3 33.6 26.8 21.3 16.9 13.5 10.8  8.6  6.8  5.5  4.4  3.5  2.8  2.3  1.8  1.5  1.2  1.0  0.8  0.7  0.6  0.5
 24.0      98.7 78.5 62.4 49.6 39.4 31.3 24.9 19.8 15.8 12.6 10.0  8.0  6.4  5.1  4.1  3.3  2.6  2.1  1.7  1.4  1.2  0.9  0.8  0.7  0.6  0.5
 25.0      92.0 73.1 58.1 46.2 36.7 29.2 23.2 18.5 14.7 11.7  9.3  7.5  6.0  4.8  3.8  3.1  2.5  2.0  1.6  1.3  1.1  0.9  0.7  0.6  0.5  0.5
```

Table B1.6 Ammonia effluent limits for the Cities of Littleton and Englewood based on a 30Q10 chronic design flow and an instream ammonia standard of 0.10 mg/l-N.

DISCHARGER: ENGLEWOOD STREAM: SOUTH PLATTE
UPSTREAM FLOW IN CFS: 36.0
UPSTREAM AMMONIA IN mg/l: 0.0
UN-IONIZED AMMONIA STANDARD IN mg/l X 10 1.0
DISCHARGE FLOW IN MGD: 28.0

DEGREES CENTIGRADE	pH																									
	6.5	6.6	6.7	6.8	6.9	7.0	7.1	7.2	7.3	7.4	7.5	7.6	7.7	7.8	7.9	8.0	8.1	8.2	8.3	8.4	8.5	8.6	8.7	8.8	8.9	9.0
3.0	*****	*****	*****	*****	*****	*****	*****	*****	87.0	69.1	55.0	43.7	34.7	27.6	22.0	17.5	13.9	11.1	8.9	7.1	5.7	4.5	3.6	2.9	2.4	1.9
4.0	*****	*****	*****	*****	*****	*****	*****	*****	80.1	63.7	50.6	40.3	32.0	25.5	20.3	16.1	12.9	10.2	8.2	6.5	5.2	4.2	3.4	2.7	2.2	1.8
5.0	*****	*****	*****	*****	*****	*****	*****	93.0	73.9	58.7	46.7	37.1	29.5	23.5	18.7	14.9	11.9	9.5	7.6	6.0	4.8	3.9	3.1	2.5	2.0	1.7
6.0	*****	*****	*****	*****	*****	*****	*****	85.7	68.2	54.2	43.1	34.2	27.2	21.7	17.3	13.7	11.0	8.7	7.0	5.6	4.5	3.6	2.9	2.3	1.9	1.5
7.0	*****	*****	*****	*****	*****	*****	99.6	79.1	62.9	50.0	39.8	31.6	25.2	20.0	15.9	12.7	10.1	8.1	6.5	5.2	4.1	3.3	2.7	2.2	1.8	1.4
8.0	*****	*****	*****	*****	*****	*****	92.0	73.1	58.1	46.2	36.7	29.2	23.2	18.5	14.7	11.7	9.4	7.5	6.0	4.8	3.8	3.1	2.5	2.0	1.6	1.3
9.0	*****	*****	*****	*****	*****	*****	85.0	67.5	53.7	42.7	33.9	27.0	21.5	17.1	13.6	10.9	8.7	6.9	5.5	4.4	3.6	2.9	2.3	1.9	1.5	1.3
10.0	*****	*****	*****	*****	*****	98.8	78.6	62.4	49.6	39.5	31.4	25.0	19.9	15.8	12.6	10.0	8.0	6.4	5.1	4.1	3.3	2.7	2.2	1.7	1.4	1.2
11.0	*****	*****	*****	*****	*****	91.4	72.7	57.8	45.9	36.5	29.0	23.1	18.4	14.6	11.7	9.3	7.4	5.9	4.8	3.8	3.1	2.5	2.0	1.6	1.3	1.1
12.0	*****	*****	*****	*****	*****	84.6	67.3	53.5	42.5	33.8	26.9	21.4	17.0	13.6	10.8	8.6	6.9	5.5	4.4	3.5	2.9	2.3	1.9	1.5	1.2	1.0
13.0	*****	*****	*****	*****	98.6	78.4	62.3	49.5	39.4	31.3	24.9	19.8	15.8	12.6	10.0	8.0	6.4	5.1	4.1	3.3	2.7	2.1	1.7	1.4	1.2	1.0
14.0	*****	*****	*****	*****	91.4	72.6	57.7	45.9	36.5	29.0	23.1	18.4	14.6	11.7	9.3	7.4	5.9	4.8	3.8	3.1	2.5	2.0	1.6	1.3	1.1	0.9
15.0	*****	*****	*****	*****	84.7	67.3	53.5	42.5	33.8	26.9	21.4	17.0	13.6	10.8	8.6	6.9	5.5	4.4	3.5	2.9	2.3	1.9	1.5	1.2	1.0	0.9
16.0	*****	*****	*****	98.8	78.5	62.4	49.6	39.5	31.4	25.0	19.9	15.8	12.6	10.0	8.0	6.4	5.1	4.1	3.3	2.7	2.2	1.7	1.4	1.2	1.0	0.8
17.0	*****	*****	*****	91.7	72.9	57.9	46.1	36.6	29.1	23.2	18.4	14.7	11.7	9.3	7.5	6.0	4.8	3.8	3.1	2.5	2.0	1.6	1.3	1.1	0.9	0.8
18.0	*****	*****	*****	85.1	67.7	53.8	42.8	34.0	27.1	21.5	17.1	13.6	10.9	8.7	6.9	5.5	4.4	3.6	2.9	2.3	1.9	1.5	1.3	1.0	0.9	0.7
19.0	*****	*****	99.5	79.1	62.9	50.0	39.7	31.6	25.1	20.0	15.9	12.7	10.1	8.1	6.5	5.2	4.1	3.3	2.7	2.2	1.8	1.4	1.2	1.0	0.8	0.7
20.0	*****	*****	92.5	73.5	58.4	46.4	36.9	29.4	23.4	18.6	14.8	11.8	9.4	7.5	6.0	4.8	3.9	3.1	2.5	2.0	1.6	1.3	1.1	0.9	0.8	0.6
21.0	*****	*****	86.0	68.4	54.3	43.2	34.4	27.3	21.7	17.3	13.8	11.0	8.8	7.0	5.6	4.5	3.6	2.9	2.3	1.9	1.5	1.3	1.0	0.9	0.7	0.6
22.0	*****	*****	80.0	63.6	50.6	40.2	32.0	25.4	20.2	16.1	12.8	10.2	8.2	6.5	5.2	4.2	3.4	2.7	2.2	1.8	1.4	1.2	1.0	0.8	0.7	0.6
23.0	*****	93.7	74.5	59.2	47.1	37.4	29.8	23.7	18.8	15.0	12.0	9.5	7.6	6.1	4.9	3.9	3.1	2.5	2.0	1.7	1.4	1.1	0.9	0.8	0.7	0.6
24.0	*****	87.3	69.4	55.1	43.8	34.8	27.7	22.1	17.6	14.0	11.1	8.9	7.1	5.7	4.5	3.6	2.9	2.4	1.9	1.6	1.3	1.1	0.9	0.7	0.6	0.5
25.0	*****	81.3	64.6	51.4	40.8	32.5	25.8	20.6	16.4	13.0	10.4	8.3	6.6	5.3	4.2	3.4	2.7	2.2	1.8	1.5	1.2	1.0	0.8	0.7	0.6	0.5

Table B1.7 Ammonia effluent limits for the Cities of Littleton and Englewood based on a 30Q3 chronic design flow and an instream ammonia standard of 0.10 mg/l-N.

```
DISCHARGER: ENGLEWOOD              STREAM: SOUTH PLATTE
UPSTREAM FLOW IN CFS:                        53.0
UPSTREAM AMMONIA IN mg/l:                     0.0
UN-IONIZED AMMONIA STANDARD IN mg/l X 10      1.0
DISCHARGE FLOW IN MGD:                       28.0

                                                                   pH
           6.5  6.6  6.7  6.8  6.9  7.0  7.1  7.2  7.3  7.4  7.5  7.6  7.7  7.8  7.9  8.0  8.1  8.2  8.3  8.4  8.5  8.6  8.7  8.8  8.9  9.0
DEGREES
CENTIGRADE
  3.0     *********************************************84.0 66.7 53.1 42.2 33.6 26.7 21.3 16.9 13.5 10.8  8.6  6.9  5.5  4.4  3.6  2.9  2.3
  4.0     ****************************************97.3 77.4 61.5 48.9 38.9 30.9 24.6 19.6 15.6 12.4  9.9  7.9  6.3  5.1  4.1  3.3  2.7  2.2
  5.0     ****************************************89.7 71.3 56.7 45.1 35.9 28.5 22.7 18.1 14.4 11.5  9.2  7.3  5.9  4.7  3.8  3.1  2.5  2.0
  6.0     ****************************************82.8 65.8 52.3 41.6 33.1 26.3 21.0 16.7 13.3 10.6  8.5  6.8  5.4  4.4  3.5  2.8  2.3  1.9
  7.0     ***********************************96.1 76.4 60.7 48.3 38.4 30.5 24.3 19.4 15.4 12.3  9.8  7.8  6.3  5.0  4.0  3.3  2.6  2.1  1.7
  8.0     ***********************************88.7 70.5 56.1 44.6 35.5 28.2 22.5 17.9 14.3 11.4  9.1  7.3  5.8  4.7  3.7  3.0  2.4  2.0  1.6
  9.0     ***********************************82.0 65.2 51.8 41.2 32.8 26.1 20.8 16.5 13.2 10.5  8.4  6.7  5.4  4.3  3.5  2.8  2.3  1.9  1.5
 10.0     ******************************95.4 75.8 60.3 47.9 38.1 30.3 24.1 19.2 15.3 12.2  9.7  7.8  6.2  5.0  4.0  3.2  2.6  2.1  1.7  1.4
 11.0     ******************************88.2 70.1 55.8 44.3 35.3 28.1 22.3 17.8 14.2 11.3  9.0  7.2  5.8  4.6  3.7  3.0  2.4  2.0  1.6  1.3
 12.0     ******************************81.7 64.9 51.6 41.0 32.6 26.0 20.7 16.5 13.1 10.5  8.4  6.7  5.4  4.3  3.5  2.8  2.3  1.8  1.5  1.2
 13.0     *************************95.2 75.6 60.1 47.8 38.0 30.2 24.1 19.2 15.3 12.2  9.7  7.8  6.2  5.0  4.0  3.2  2.6  2.1  1.7  1.4  1.2
 14.0     *************************88.2 70.1 55.7 44.3 35.2 28.0 22.3 17.8 14.2 11.3  9.0  7.2  5.8  4.6  3.7  3.0  2.4  2.0  1.6  1.3  1.1
 15.0     *************************81.7 65.0 51.6 41.1 32.7 26.0 20.7 16.5 13.1 10.5  8.4  6.7  5.4  4.3  3.5  2.8  2.3  1.8  1.5  1.2  1.0
 16.0     ********************95.4 75.8 60.3 47.9 38.1 30.3 24.1 19.2 15.3 12.2  9.7  7.8  6.2  5.0  4.0  3.2  2.6  2.1  1.7  1.4  1.2  1.0
 17.0     ********************88.5 70.4 55.9 44.5 35.4 28.1 22.4 17.8 14.2 11.3  9.1  7.2  5.8  4.6  3.7  3.0  2.4  2.0  1.6  1.3  1.1  0.9
 18.0     ********************82.2 65.3 51.9 41.3 32.8 26.1 20.8 16.6 13.2 10.5  8.4  6.7  5.4  4.3  3.5  2.8  2.3  1.9  1.5  1.3  1.0  0.9
 19.0     ***************96.0 76.3 60.7 48.2 38.4 30.5 24.3 19.3 15.4 12.3  9.8  7.8  6.3  5.0  4.0  3.3  2.6  2.1  1.7  1.4  1.2  1.0  0.8
 20.0     ***************89.3 71.0 56.4 44.9 35.7 28.4 22.6 18.0 14.3 11.4  9.1  7.3  5.8  4.7  3.8  3.0  2.5  2.0  1.6  1.3  1.1  0.9  0.8
 21.0     ***************83.0 66.0 52.5 41.7 33.2 26.4 21.0 16.7 13.3 10.6  8.5  6.8  5.4  4.4  3.5  2.8  2.3  1.9  1.5  1.3  1.1  0.9  0.7
 22.0     **********97.2 77.2 61.4 48.8 38.8 30.9 24.6 19.6 15.6 12.4  9.9  7.9  6.3  5.1  4.1  3.3  2.7  2.2  1.8  1.4  1.2  1.0  0.8  0.7
 23.0     **********90.4 71.9 57.1 45.4 36.1 28.8 22.9 18.2 14.5 11.6  9.2  7.4  5.9  4.7  3.8  3.1  2.5  2.0  1.7  1.4  1.1  0.9  0.8  0.7
 24.0     **********84.2 66.9 53.2 42.3 33.7 26.8 21.3 17.0 13.5 10.8  8.6  6.9  5.5  4.4  3.6  2.9  2.3  1.9  1.6  1.3  1.1  0.9  0.8  0.6
 25.0     *****98.7 78.5 62.4 49.6 39.4 31.4 25.0 19.9 15.8 12.6 10.1  8.0  6.4  5.2  4.1  3.3  2.7  2.2  1.8  1.5  1.2  1.0  0.8  0.7  0.6
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Table B1.8 Ammonia effluent limits for the Cities of Littleton and Englewood based on an upstream ammonia concentration of 0.10 mg/l-N, a 7Q10 chronic design flow, and an instream ammonia standard of 0.06 mg/l-N.

DISCHARGER: ENGLEWOOD STREAM: South Platte River
UPSTREAM FLOW IN CFS: 28.0
UPSTREAM AMMONIA IN mg/l: 0.1
UN-IONIZED AMMONIA STANDARD IN mg/l X 10 0.6
DISCHARGE FLOW IN MGD: 28.0

pH

DEGREES CENTIGRADE	6.5	6.6	6.7	6.8	6.9	7.0	7.1	7.2	7.3	7.4	7.5	7.6	7.7	7.8	7.9	8.0	8.1	8.2	8.3	8.4	8.5	8.6	8.7	8.8	8.9	9.0
3.0	*****	*****	*****	*****	*****	93.5	74.3	59.0	46.9	37.2	29.6	23.5	18.7	14.8	11.8	9.4	7.5	5.9	4.7	3.8	3.0	2.4	1.9	1.5	1.2	1.0
4.0	*****	*****	*****	*****	*****	86.1	68.4	54.3	43.2	34.3	27.3	21.7	17.2	13.7	10.9	8.6	6.9	5.5	4.3	3.5	2.8	2.2	1.8	1.4	1.1	0.9
5.0	*****	*****	*****	*****	99.9	79.4	63.0	50.1	39.8	31.6	25.1	20.0	15.9	12.6	10.0	8.0	6.3	5.0	4.0	3.2	2.5	2.0	1.6	1.3	1.0	0.8
6.0	*****	*****	*****	*****	92.1	73.2	58.1	46.2	36.7	29.2	23.2	18.4	14.6	11.6	9.2	7.4	5.8	4.7	3.7	2.9	2.3	1.9	1.5	1.2	1.0	0.8
7.0	*****	*****	*****	*****	85.0	67.5	53.7	42.6	33.9	26.9	21.4	17.0	13.5	10.7	8.5	6.8	5.4	4.3	3.4	2.7	2.2	1.7	1.4	1.1	0.9	0.7
8.0	*****	*****	*****	98.8	78.5	62.4	49.5	39.4	31.3	24.8	19.7	15.7	12.5	9.9	7.9	6.3	5.0	4.0	3.2	2.5	2.0	1.6	1.3	1.0	0.8	0.7
9.0	*****	*****	*****	91.3	72.5	57.6	45.8	36.4	28.9	23.0	18.2	14.5	11.5	9.2	7.3	5.8	4.6	3.7	2.9	2.3	1.9	1.5	1.2	0.9	0.8	0.6
10.0	*****	*****	*****	84.4	67.0	53.3	42.3	33.6	26.7	21.2	16.9	13.4	10.7	8.5	6.7	5.4	4.3	3.4	2.7	2.2	1.7	1.4	1.1	0.9	0.7	0.6
11.0	*****	*****	98.3	78.1	62.0	49.3	39.1	31.1	24.7	19.6	15.6	12.4	9.9	7.8	6.2	5.0	3.9	3.1	2.5	2.0	1.6	1.3	1.0	0.8	0.7	0.5
12.0	*****	*****	90.9	72.2	57.4	45.6	36.2	28.8	22.9	18.2	14.4	11.5	9.1	7.3	5.8	4.6	3.7	2.9	2.3	1.8	1.5	1.2	0.9	0.8	0.6	0.5
13.0	*****	*****	84.2	66.9	53.1	42.2	33.5	26.6	21.2	16.8	13.4	10.6	8.4	6.7	5.3	4.3	3.4	2.7	2.1	1.7	1.4	1.1	0.9	0.7	0.6	0.5
14.0	*****	98.2	78.0	62.0	49.2	39.1	31.1	24.7	19.6	15.6	12.4	9.8	7.8	6.2	5.0	3.9	3.1	2.5	2.0	1.6	1.3	1.0	0.8	0.7	0.5	0.4
15.0	*****	91.0	72.3	57.4	45.6	36.2	28.8	22.9	18.2	14.4	11.5	9.1	7.3	5.8	4.6	3.7	2.9	2.3	1.8	1.5	1.2	0.9	0.8	0.6	0.5	0.4
16.0	*****	84.4	67.0	53.3	42.3	33.6	26.7	21.2	16.9	13.4	10.7	8.5	6.7	5.4	4.3	3.4	2.7	2.2	1.7	1.4	1.1	0.9	0.7	0.6	0.5	0.4
17.0	98.6	78.3	62.2	49.4	39.3	31.2	24.8	19.7	15.6	12.4	9.9	7.9	6.3	5.0	4.0	3.1	2.5	2.0	1.6	1.3	1.0	0.8	0.7	0.5	0.4	0.3
18.0	91.5	72.7	57.7	45.9	36.4	29.0	23.0	18.3	14.5	11.5	9.2	7.3	5.8	4.6	3.7	2.9	2.3	1.9	1.5	1.2	0.9	0.8	0.6	0.5	0.4	0.3
19.0	85.0	67.5	53.6	42.6	33.8	26.9	21.4	17.0	13.5	10.7	8.5	6.8	5.4	4.3	3.4	2.7	2.2	1.7	1.4	1.1	0.9	0.7	0.6	0.5	0.4	0.3
20.0	79.0	62.7	49.8	39.6	31.5	25.0	19.9	15.8	12.5	10.0	7.9	6.3	5.0	4.0	3.2	2.5	2.0	1.6	1.3	1.0	0.8	0.7	0.5	0.4	0.3	0.3
21.0	73.4	58.3	46.3	36.8	29.2	23.2	18.5	14.7	11.7	9.3	7.4	5.9	4.7	3.7	3.0	2.4	1.9	1.5	1.2	1.0	0.8	0.6	0.5	0.4	0.3	0.3
22.0	68.3	54.3	43.1	34.2	27.2	21.6	17.2	13.7	10.9	8.6	6.8	5.5	4.3	3.5	2.8	2.2	1.7	1.4	1.1	0.9	0.7	0.6	0.5	0.4	0.3	0.2
23.0	63.6	50.5	40.1	31.9	25.3	20.1	16.0	12.7	10.1	8.0	6.4	5.1	4.0	3.2	2.6	2.0	1.6	1.3	1.0	0.8	0.7	0.5	0.4	0.4	0.3	0.2
24.0	59.2	47.0	37.3	29.7	23.6	18.7	14.9	11.8	9.4	7.5	5.9	4.7	3.8	3.0	2.4	1.9	1.5	1.2	1.0	0.8	0.6	0.5	0.4	0.3	0.3	0.2
25.0	55.1	43.8	34.8	27.6	22.0	17.5	13.9	11.0	8.8	7.0	5.5	4.4	3.5	2.8	2.2	1.8	1.4	1.1	0.9	0.7	0.6	0.5	0.4	0.3	0.3	0.2

Table B1.9. Ammonia effluent limits for the Cities of Littleton and Englewood based on a 1Q10 acute flow.

DISCHARGER: ENGLEWOOD STREAM: SOUTH PLATTE
UPSTREAM FLOW IN CFS: 24.0
UPSTREAM AMMONIA IN mg/l: 0.0
UN-IONIZED AMMONIA STANDARD IN mg/l X 10 2.0
DISCHARGE FLOW IN MGD: 28.0

pH

DEGREES CENTIGRADE	6.5	6.6	6.7	6.8	6.9	7.0	7.1	7.2	7.3	7.4	7.5	7.6	7.7	7.8	7.9	8.0	8.1	8.2	8.3	8.4	8.5	8.6	8.7	8.8	8.9	9.0
3.0	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	93.3	74.2	59.0	46.9	37.3	29.7	23.7	18.9	15.0	12.0	9.6	7.7	6.2	5.0	4.0	3.3
4.0	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	85.9	68.3	54.3	43.2	34.4	27.4	21.8	17.4	13.9	11.1	8.9	7.1	5.7	4.6	3.7	3.0
5.0	*****	*****	*****	*****	*****	*****	*****	*****	*****	99.7	79.2	63.0	50.1	39.9	31.7	25.3	20.1	16.1	12.8	10.2	8.2	6.6	5.3	4.3	3.5	2.8
6.0	*****	*****	*****	*****	*****	*****	*****	*****	*****	92.0	73.1	58.1	46.2	36.8	29.3	23.3	18.6	14.8	11.8	9.5	7.6	6.1	4.9	4.0	3.2	2.6
7.0	*****	*****	*****	*****	*****	*****	*****	*****	*****	84.9	67.5	53.7	42.7	34.0	27.1	21.6	17.2	13.7	11.0	8.8	7.0	5.6	4.5	3.7	3.0	2.4
8.0	*****	*****	*****	*****	*****	*****	*****	*****	98.6	78.4	62.3	49.6	39.4	31.4	25.0	19.9	15.9	12.7	10.1	8.1	6.5	5.2	4.2	3.4	2.8	2.3
9.0	*****	*****	*****	*****	*****	*****	*****	*****	91.1	72.4	57.6	45.8	36.5	29.0	23.1	18.4	14.7	11.7	9.4	7.5	6.0	4.9	3.9	3.2	2.6	2.1
10.0	*****	*****	*****	*****	*****	*****	*****	*****	84.2	67.0	53.3	42.4	33.7	26.9	21.4	17.1	13.6	10.9	8.7	7.0	5.6	4.5	3.7	3.0	2.4	2.0
11.0	*****	*****	*****	*****	*****	*****	*****	98.0	77.9	62.0	49.3	39.2	31.2	24.9	19.8	15.8	12.6	10.1	8.1	6.5	5.2	4.2	3.4	2.8	2.3	1.9
12.0	*****	*****	*****	*****	*****	*****	*****	90.7	72.1	57.4	45.6	36.3	28.9	23.0	18.4	14.6	11.7	9.4	7.5	6.0	4.8	3.9	3.2	2.6	2.1	1.7
13.0	*****	*****	*****	*****	*****	*****	*****	84.0	66.8	53.1	42.3	33.6	26.8	21.3	17.0	13.6	10.9	8.7	7.0	5.6	4.5	3.6	3.0	2.4	2.0	1.6
14.0	*****	*****	*****	*****	*****	*****	98.0	77.9	61.9	49.2	39.2	31.2	24.8	19.8	15.8	12.6	10.1	8.1	6.5	5.2	4.2	3.4	2.8	2.3	1.9	1.5
15.0	*****	*****	*****	*****	*****	*****	90.8	72.2	57.4	45.7	36.3	28.9	23.0	18.4	14.7	11.7	9.4	7.5	6.0	4.8	3.9	3.2	2.6	2.1	1.7	1.5
16.0	*****	*****	*****	*****	*****	*****	84.2	67.0	53.3	42.4	33.7	26.8	21.4	17.1	13.6	10.9	8.7	7.0	5.6	4.5	3.7	3.0	2.4	2.0	1.6	1.4
17.0	*****	*****	*****	*****	*****	98.3	78.2	62.2	49.4	39.3	31.3	24.9	19.9	15.8	12.7	10.1	8.1	6.5	5.2	4.2	3.4	2.8	2.3	1.9	1.5	1.3
18.0	*****	*****	*****	*****	*****	91.3	72.6	57.7	45.9	36.5	29.1	23.2	18.5	14.7	11.8	9.4	7.5	6.1	4.9	3.9	3.2	2.6	2.1	1.8	1.5	1.2
19.0	*****	*****	*****	*****	*****	84.8	67.4	53.6	42.7	34.0	27.0	21.5	17.2	13.7	11.0	8.8	7.0	5.6	4.5	3.7	3.0	2.4	2.0	1.7	1.4	1.2
20.0	*****	*****	*****	*****	99.2	78.8	62.7	49.9	39.7	31.6	25.1	20.0	16.0	12.8	10.2	8.2	6.5	5.3	4.2	3.4	2.8	2.3	1.9	1.6	1.3	1.1
21.0	*****	*****	*****	*****	92.2	73.3	58.3	46.4	36.9	29.4	23.4	18.7	14.9	11.9	9.5	7.6	6.1	4.9	4.0	3.2	2.6	2.1	1.8	1.5	1.2	1.0
22.0	*****	*****	*****	*****	85.8	68.2	54.3	43.2	34.3	27.3	21.8	17.4	13.9	11.1	8.9	7.1	5.7	4.6	3.7	3.0	2.5	2.0	1.7	1.4	1.2	1.0
23.0	*****	*****	*****	*****	79.9	63.5	50.5	40.2	32.0	25.5	20.3	16.2	12.9	10.3	8.3	6.6	5.3	4.3	3.5	2.8	2.3	1.9	1.6	1.3	1.1	0.9
24.0	*****	*****	*****	93.6	74.4	59.2	47.1	37.4	29.8	23.7	18.9	15.1	12.1	9.6	7.7	6.2	5.0	4.0	3.3	2.7	2.2	1.8	1.5	1.2	1.1	0.9
25.0	*****	*****	*****	87.2	69.3	55.1	43.9	34.9	27.8	22.1	17.6	14.1	11.2	9.0	7.2	5.8	4.7	3.8	3.1	2.5	2.0	1.7	1.4	1.2	1.0	0.9

Table B1.10. Ammonia effluent limits for the Cities of Littleton and Englewood based on a 1Q3 acute design flow.

DISCHARGER: ENGLEWOOD	STREAM:	South Platte River
UPSTREAM FLOW IN CFS:		35.0
UPSTREAM AMMONIA IN mg/l:		0.0
UN-IONIZED AMMONIA STANDARD IN mg/l X 10		2.0
DISCHARGE FLOW IN MGD:		28.0

DEGREES CENTIGRADE	pH 6.5	6.6	6.7	6.8	6.9	7.0	7.1	7.2	7.3	7.4	7.5	7.6	7.7	7.8	7.9	8.0	8.1	8.2	8.3	8.4	8.5	8.6	8.7	8.8	8.9	9.0
3.0	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	86.3	68.6	54.6	43.4	34.6	27.5	21.9	17.5	14.0	11.2	9.0	7.2	5.8	4.7	3.8
4.0	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	79.5	63.2	50.3	40.0	31.9	25.4	20.2	16.2	12.9	10.3	8.3	6.6	5.4	4.3	3.5
5.0	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	92.2	73.3	58.3	46.4	36.9	29.4	23.4	18.7	14.9	11.9	9.5	7.7	6.2	5.0	4.0	3.3
6.0	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	85.0	67.6	53.8	42.8	34.1	27.1	21.6	17.3	13.8	11.0	8.8	7.1	5.7	4.6	3.7	3.0
7.0	*****	*****	*****	*****	*****	*****	*****	*****	*****	98.7	78.5	62.4	49.7	39.5	31.5	25.1	20.0	16.0	12.7	10.2	8.2	6.6	5.3	4.3	3.5	2.8
8.0	*****	*****	*****	*****	*****	*****	*****	*****	*****	91.2	72.5	57.7	45.9	36.5	29.1	23.2	18.5	14.8	11.8	9.4	7.6	6.1	4.9	4.0	3.2	2.6
9.0	*****	*****	*****	*****	*****	*****	*****	*****	*****	84.3	67.0	53.3	42.4	33.8	26.9	21.4	17.1	13.7	10.9	8.8	7.0	5.7	4.6	3.7	3.0	2.5
10.0	*****	*****	*****	*****	*****	*****	*****	*****	98.0	77.9	62.0	49.3	39.2	31.2	24.9	19.8	15.8	12.7	10.1	8.1	6.5	5.3	4.2	3.4	2.8	2.3
11.0	*****	*****	*****	*****	*****	*****	*****	*****	90.7	72.1	57.3	45.6	36.3	28.9	23.0	18.4	14.7	11.7	9.4	7.5	6.1	4.9	4.0	3.2	2.6	2.2
12.0	*****	*****	*****	*****	*****	*****	*****	*****	83.9	66.7	53.1	42.2	33.6	26.8	21.4	17.0	13.6	10.9	8.7	7.0	5.6	4.6	3.7	3.0	2.5	2.0
13.0	*****	*****	*****	*****	*****	*****	*****	97.8	77.7	61.8	49.2	39.1	31.2	24.8	19.8	15.8	12.6	10.1	8.1	6.5	5.2	4.2	3.4	2.8	2.3	1.9
14.0	*****	*****	*****	*****	*****	*****	*****	90.6	72.0	57.3	45.6	36.3	28.9	23.0	18.4	14.7	11.7	9.4	7.5	6.1	4.9	4.0	3.2	2.6	2.2	1.8
15.0	*****	*****	*****	*****	*****	*****	*****	84.0	66.8	53.1	42.3	33.7	26.8	21.4	17.0	13.6	10.9	8.7	7.0	5.6	4.6	3.7	3.0	2.5	2.0	1.7
16.0	*****	*****	*****	*****	*****	*****	98.0	77.9	62.0	49.3	39.2	31.2	24.9	19.8	15.8	12.7	10.1	8.1	6.5	5.3	4.2	3.4	2.8	2.3	1.9	1.6
17.0	*****	*****	*****	*****	*****	*****	90.9	72.3	57.5	45.8	36.4	29.0	23.1	18.4	14.7	11.8	9.4	7.6	6.1	4.9	4.0	3.2	2.6	2.2	1.8	1.5
18.0	*****	*****	*****	*****	*****	*****	84.5	67.2	53.4	42.5	33.8	27.0	21.5	17.1	13.7	10.9	8.8	7.0	5.7	4.6	3.7	3.0	2.5	2.0	1.7	1.4
19.0	*****	*****	*****	*****	*****	98.7	78.5	62.4	49.6	39.5	31.5	25.1	20.0	15.9	12.7	10.2	8.2	6.6	5.3	4.3	3.5	2.8	2.3	1.9	1.6	1.3
20.0	*****	*****	*****	*****	*****	91.7	72.9	58.0	46.2	36.7	29.3	23.3	18.6	14.8	11.9	9.5	7.6	6.1	4.9	4.0	3.3	2.7	2.2	1.8	1.5	1.3
21.0	*****	*****	*****	*****	*****	85.3	67.8	54.0	42.9	34.2	27.2	21.7	17.3	13.8	11.1	8.9	7.1	5.7	4.6	3.7	3.0	2.5	2.1	1.7	1.4	1.2
22.0	*****	*****	*****	*****	99.8	79.4	63.1	50.2	40.0	31.8	25.3	20.2	16.1	12.9	10.3	8.3	6.6	5.3	4.3	3.5	2.9	2.3	1.9	1.6	1.4	1.2
23.0	*****	*****	*****	*****	92.9	73.9	58.8	46.8	37.2	29.6	23.6	18.8	15.0	12.0	9.6	7.7	6.2	5.0	4.0	3.3	2.7	2.2	1.8	1.5	1.3	1.1
24.0	*****	*****	*****	*****	86.5	68.8	54.7	43.6	34.7	27.6	22.0	17.6	14.0	11.2	9.0	7.2	5.8	4.7	3.8	3.1	2.5	2.1	1.7	1.4	1.2	1.0
25.0	*****	*****	*****	*****	80.6	64.1	51.0	40.6	32.3	25.7	20.5	16.4	13.1	10.5	8.4	6.7	5.4	4.4	3.6	2.9	2.4	2.0	1.6	1.4	1.2	1.0

Table B2.1 Ammonia effluent limits for the City of Boulder based on a 7Q10 chronic design flow and an instream ammonia standard of 0.06 mg/l-N.

DISCHARGER: BOULDER, COLORADO STREAM: BOULDER CREEK
UPSTREAM FLOW IN CFS: 8.4
UPSTREAM AMMONIA IN mg/l: 0.0
UN-IONIZED AMMONIA STANDARD IN mg/l x 10 0.6
DISCHARGE FLOW IN MGD: 13.6

	pH																								
DEGREES CENTIGRADE	6.5	6.6	6.7	6.8	6.9	7.0	7.1	7.2	7.3	7.4	7.5	7.6	7.7	7.8	7.9	8.0	8.1	8.2	8.3	8.4	8.5	8.6	8.7	8.8	8.9	9.0
3.0	*****	*****	*****	*****	96.4	75.5	60.9	48.4	38.4	30.5	24.3	19.3	15.3	12.2	9.7	7.7	6.2	4.9	3.9	3.1	2.5	2.0	1.6	1.3	1.0	0.8
4.0	*****	*****	*****	*****	88.8	70.6	56.1	44.5	35.4	28.1	22.4	17.8	14.1	11.3	9.0	7.1	5.7	4.5	3.6	2.9	2.3	1.9	1.5	1.2	1.0	0.8
5.0	*****	*****	*****	*****	81.9	65.0	51.7	41.1	32.6	25.9	20.6	16.4	13.0	10.4	8.3	6.6	5.2	4.2	3.3	2.7	2.1	1.7	1.4	1.1	0.9	0.7
6.0	*****	*****	*****	95.0	75.5	60.0	47.7	37.9	30.1	23.9	19.0	15.1	12.0	9.6	7.6	6.1	4.8	3.9	3.1	2.5	2.0	1.6	1.3	1.0	0.8	0.7
7.0	*****	*****	*****	87.7	69.7	55.4	44.0	35.0	27.8	22.1	17.6	14.0	11.1	8.8	7.0	5.6	4.5	3.6	2.9	2.3	1.8	1.5	1.2	1.0	0.8	0.6
8.0	*****	*****	*****	81.0	64.3	51.1	40.6	32.3	25.7	20.4	16.2	12.9	10.3	8.2	6.5	5.2	4.1	3.3	2.6	2.1	1.7	1.4	1.1	0.9	0.7	0.6
9.0	*****	*****	94.2	74.8	59.4	47.2	37.5	29.8	23.7	18.9	15.0	11.9	9.5	7.6	6.0	4.8	3.8	3.1	2.4	2.0	1.6	1.3	1.0	0.8	0.7	0.6
10.0	*****	*****	87.0	69.2	54.9	43.7	34.7	27.6	21.9	17.4	13.9	11.0	8.8	7.0	5.6	4.4	3.5	2.8	2.3	1.8	1.5	1.2	1.0	0.8	0.6	0.5
11.0	*****	*****	80.5	64.0	50.8	40.4	32.1	25.5	20.3	16.1	12.8	10.2	8.1	6.5	5.2	4.1	3.3	2.6	2.1	1.7	1.4	1.1	0.9	0.7	0.6	0.5
12.0	*****	93.8	74.5	59.2	47.0	37.4	29.7	23.6	18.8	14.9	11.9	9.4	7.5	6.0	4.8	3.8	3.0	2.4	2.0	1.6	1.3	1.0	0.8	0.7	0.6	0.5
13.0	*****	86.8	69.0	54.8	43.6	34.6	27.5	21.9	17.4	13.8	11.0	8.8	7.0	5.6	4.4	3.5	2.8	2.3	1.8	1.5	1.2	0.9	0.8	0.6	0.5	0.4
14.0	*****	80.4	63.9	50.8	40.4	32.1	25.5	20.3	16.1	12.8	10.2	8.1	6.5	5.2	4.1	3.3	2.6	2.1	1.7	1.4	1.1	0.9	0.7	0.6	0.5	0.4
15.0	93.8	74.6	59.2	47.1	37.4	29.7	23.6	18.8	14.9	11.9	9.5	7.5	6.0	4.8	3.8	3.0	2.4	2.0	1.6	1.3	1.0	0.8	0.7	0.6	0.5	0.4
16.0	87.0	69.1	54.9	43.7	34.7	27.6	21.9	17.4	13.9	11.0	8.8	7.0	5.6	4.4	3.5	2.8	2.3	1.8	1.5	1.2	1.0	0.8	0.6	0.5	0.4	0.4
17.0	80.7	64.2	51.0	40.5	32.2	25.6	20.3	16.2	12.9	10.2	8.1	6.5	5.2	4.1	3.3	2.6	2.1	1.7	1.4	1.1	0.9	0.7	0.6	0.5	0.4	0.3
18.0	75.0	59.6	47.3	37.6	29.9	23.8	18.9	15.0	11.9	9.5	7.6	6.0	4.8	3.8	3.1	2.4	2.0	1.6	1.3	1.0	0.8	0.7	0.6	0.5	0.4	0.3
19.0	69.6	55.3	44.0	34.9	27.8	22.1	17.6	14.0	11.1	8.8	7.0	5.6	4.5	3.6	2.8	2.3	1.8	1.5	1.2	1.0	0.8	0.6	0.5	0.4	0.4	0.3
20.0	64.7	51.4	40.9	32.5	25.8	20.5	16.3	13.0	10.3	8.2	6.5	5.2	4.2	3.3	2.7	2.1	1.7	1.4	1.1	0.9	0.7	0.6	0.5	0.4	0.3	0.3
21.0	60.2	47.8	38.0	30.2	24.0	19.1	15.2	12.1	9.6	7.6	6.1	4.9	3.9	3.1	2.5	2.0	1.6	1.3	1.0	0.8	0.7	0.6	0.5	0.4	0.3	0.3
22.0	56.0	44.5	35.3	28.1	22.3	17.8	14.1	11.2	8.9	7.1	5.7	4.5	3.6	2.9	2.3	1.8	1.5	1.2	1.0	0.8	0.6	0.5	0.4	0.4	0.3	0.3
23.0	52.1	41.4	32.9	26.1	20.8	16.5	13.1	10.5	8.3	6.6	5.3	4.2	3.4	2.7	2.2	1.7	1.4	1.1	0.9	0.7	0.6	0.5	0.4	0.3	0.3	0.2
24.0	48.5	38.5	30.6	24.4	19.4	15.4	12.2	9.7	7.8	6.2	4.9	3.9	3.1	2.5	2.0	1.6	1.3	1.0	0.8	0.7	0.6	0.5	0.4	0.3	0.3	0.2
25.0	45.2	35.9	28.5	22.7	18.0	14.3	11.4	9.1	7.2	5.8	4.6	3.7	2.9	2.3	1.9	1.5	1.2	1.0	0.8	0.6	0.5	0.4	0.4	0.3	0.3	0.2

Table B2.2 Ammonia effluent limits for the City of Boulder based on a 30Q10 chronic design flow and an instream ammonia standard of 0.06 mg/l-N.

```
DISCHARGER:   BOULDER, COLORADO   STREAM:   BOULDER CREEK
UPSTREAM FLOW IN CFS:                       14.0
UPSTREAM AMMONIA IN mg/l:                    0.0
UN-IONIZED AMMONIA STANDARD IN mg/l X 10     0.6
DISCHARGE FLOW IN MGD:                      15.6

                                                               pH
         6.5  6.6  6.7  6.8  6.9  7.0  7.1  7.2  7.3  7.4  7.5  7.6  7.7  7.8  7.9  8.0  8.1  8.2  8.3  8.4  8.5  8.6  8.7  8.8  8.9  9.0
DEGREES
CENTIGRADE
  3.0    *************************89.8 71.3 56.7 45.0 35.8 28.5 22.6 18.0 14.3 11.4  9.1  7.2  5.8  4.6  3.7  2.9  2.3  1.9  1.5  1.2  1.0
  4.0    *************************82.7 65.7 52.2 41.5 33.0 26.2 20.8 16.6 13.2 10.5  8.4  6.7  5.3  4.2  3.4  2.7  2.2  1.7  1.4  1.1  0.9
  5.0    ********************95.9 76.2 60.6 48.1 38.3 30.4 24.2 19.2 15.3 12.2  9.7  7.7  6.1  4.9  3.9  3.1  2.5  2.0  1.6  1.3  1.1  0.9
  6.0    ********************88.5 70.3 55.9 44.4 35.3 28.0 22.3 17.7 14.1 11.2  8.9  7.1  5.7  4.5  3.6  2.9  2.3  1.9  1.5  1.2  1.0  0.8
  7.0    ********************81.7 64.9 51.6 41.0 32.6 25.9 20.6 16.4 13.0 10.4  8.3  6.6  5.2  4.2  3.3  2.7  2.1  1.7  1.4  1.1  0.9  0.7
  8.0    ***************94.9 75.4 59.9 47.6 37.8 30.1 23.9 19.0 15.1 12.0  9.6  7.6  6.1  4.8  3.9  3.1  2.5  2.0  1.6  1.3  1.0  0.8  0.7
  9.0    ***************87.7 69.7 55.4 44.0 35.0 27.8 22.1 17.6 14.0 11.1  8.9  7.1  5.6  4.5  3.6  2.9  2.3  1.8  1.5  1.2  1.0  0.8  0.6
 10.0    ***************81.1 64.4 51.2 40.7 32.3 25.7 20.4 16.2 12.9 10.3  8.2  6.5  5.2  4.2  3.3  2.7  2.1  1.7  1.4  1.1  0.9  0.7  0.6
 11.0    **********94.4 75.0 59.6 47.3 37.6 29.9 23.8 18.9 15.0 12.0  9.5  7.6  6.0  4.8  3.8  3.1  2.5  2.0  1.6  1.3  1.0  0.8  0.7  0.6
 12.0    **********87.3 69.4 55.1 43.8 34.8 27.7 22.0 17.5 13.9 11.1  8.8  7.0  5.6  4.5  3.6  2.9  2.3  1.8  1.5  1.2  1.0  0.8  0.6  0.5
 13.0    **********80.9 64.2 51.1 40.6 32.2 25.6 20.4 16.2 12.9 10.3  8.2  6.5  5.2  4.1  3.3  2.6  2.1  1.7  1.4  1.1  0.9  0.7  0.6  0.5
 14.0    *****94.3 74.9 59.5 47.3 37.6 29.9 23.8 18.9 15.0 12.0  9.5  7.6  6.0  4.8  3.8  3.1  2.5  2.0  1.6  1.3  1.0  0.8  0.7  0.6  0.5
 15.0    *****87.4 69.4 55.2 43.8 34.8 27.7 22.0 17.5 13.9 11.1  8.8  7.0  5.6  4.5  3.6  2.9  2.3  1.8  1.5  1.2  1.0  0.8  0.6  0.5  0.4
 16.0    *****81.0 64.4 51.2 40.7 32.3 25.7 20.4 16.2 12.9 10.3  8.2  6.5  5.2  4.2  3.3  2.7  2.1  1.7  1.4  1.1  0.9  0.7  0.6  0.5  0.4
 17.0    94.6 75.2 59.8 47.5 37.7 30.0 23.8 19.0 15.1 12.0  9.6  7.6  6.1  4.8  3.9  3.1  2.5  2.0  1.6  1.3  1.0  0.8  0.7  0.6  0.5  0.4
 18.0    87.9 69.8 55.5 44.1 35.0 27.9 22.1 17.6 14.0 11.1  8.9  7.1  5.6  4.5  3.6  2.9  2.3  1.8  1.5  1.2  1.0  0.8  0.6  0.5  0.4  0.4
 19.0    81.6 64.8 51.5 41.0 32.5 25.9 20.6 16.4 13.0 10.4  8.2  6.6  5.2  4.2  3.3  2.7  2.1  1.7  1.4  1.1  0.9  0.7  0.6  0.5  0.4  0.4
 20.0    75.8 60.3 47.9 38.1 30.3 24.0 19.1 15.2 12.1  9.6  7.7  6.1  4.9  3.9  3.1  2.5  2.0  1.6  1.3  1.0  0.9  0.7  0.6  0.5  0.4  0.3
 21.0    70.5 56.0 44.5 35.4 28.1 22.4 17.8 14.1 11.3  9.0  7.1  5.7  4.5  3.6  2.9  2.3  1.9  1.5  1.2  1.0  0.8  0.7  0.5  0.4  0.4  0.3
 22.0    65.6 52.1 41.4 32.9 26.2 20.8 16.5 13.2 10.5  8.3  6.6  5.3  4.2  3.4  2.7  2.2  1.7  1.4  1.1  0.9  0.7  0.6  0.5  0.4  0.4  0.3
 23.0    61.1 48.5 38.6 30.6 24.4 19.4 15.4 12.3  9.8  7.8  6.2  4.9  3.9  3.2  2.5  2.0  1.6  1.3  1.1  0.9  0.7  0.6  0.5  0.4  0.3  0.3
 24.0    56.9 45.2 35.9 28.5 22.7 18.0 14.4 11.4  9.1  7.2  5.8  4.6  3.7  2.9  2.4  1.9  1.5  1.2  1.0  0.8  0.7  0.5  0.5  0.4  0.3  0.3
 25.0    53.0 42.1 33.5 26.6 21.1 16.8 13.4 10.6  8.5  6.8  5.4  4.3  3.4  2.7  2.2  1.8  1.4  1.1  0.9  0.8  0.6  0.5  0.4  0.4  0.3  0.3
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Table B2.3 Ammonia effluent limits for the City of Boulder based on a 30Q3 chronic design flow and an instream ammonia standard of 0.06 mg/l-N.

DISCHARGER: BOULDER, COLORADO STREAM: BOULDER CREEK
UPSTREAM FLOW IN CFS: 20.0
UPSTREAM AMMONIA IN mg/l: 0.0
UN-IONIZED AMMONIA STANDARD IN mg/l X 10 0.6
DISCHARGE FLOW IN MGD: 15.6

pH

DEGREES CENTIGRADE	6.5	6.6	6.7	6.8	6.9	7.0	7.1	7.2	7.3	7.4	7.5	7.6	7.7	7.8	7.9	8.0	8.1	8.2	8.3	8.4	8.5	8.6	8.7	8.8	8.9	9.0
3.0	*****	*****	*****	*****	*****	*****	82.5	65.6	52.1	41.4	32.9	26.2	20.8	16.6	13.2	10.5	8.4	6.7	5.3	4.2	3.4	2.7	2.2	1.8	1.4	1.1
4.0	*****	*****	*****	*****	*****	95.7	76.0	60.4	48.0	38.2	30.3	24.1	19.2	15.3	12.1	9.7	7.7	6.1	4.9	3.9	3.1	2.5	2.0	1.6	1.3	1.1
5.0	*****	*****	*****	*****	*****	88.2	70.1	55.7	44.3	35.2	28.0	22.2	17.7	14.1	11.2	8.9	7.1	5.7	4.5	3.6	2.9	2.3	1.9	1.5	1.2	1.0
6.0	*****	*****	*****	*****	*****	81.4	64.7	51.4	40.8	32.5	25.8	20.5	16.3	13.0	10.3	8.2	6.6	5.2	4.2	3.3	2.7	2.2	1.7	1.4	1.1	0.9
7.0	*****	*****	*****	*****	94.5	75.1	59.7	47.4	37.7	30.0	23.8	18.9	15.1	12.0	9.5	7.6	6.1	4.8	3.9	3.1	2.5	2.0	1.6	1.3	1.1	0.9
8.0	*****	*****	*****	*****	87.3	69.3	55.1	43.8	34.8	27.7	22.0	17.5	13.9	11.1	8.8	7.0	5.6	4.5	3.6	2.9	2.3	1.8	1.5	1.2	1.0	0.8
9.0	*****	*****	*****	*****	80.6	64.1	50.9	40.5	32.2	25.6	20.3	16.2	12.9	10.2	8.2	6.5	5.2	4.1	3.3	2.7	2.1	1.7	1.4	1.1	0.9	0.7
10.0	*****	*****	*****	93.8	74.5	59.2	47.1	37.4	29.7	23.6	18.8	15.0	11.9	9.5	7.6	6.0	4.8	3.8	3.1	2.5	2.0	1.6	1.3	1.0	0.9	0.7
11.0	*****	*****	*****	86.8	68.9	54.8	43.5	34.6	27.5	21.9	17.4	13.8	11.0	8.8	7.0	5.6	4.5	3.6	2.9	2.3	1.8	1.5	1.2	1.0	0.8	0.7
12.0	*****	*****	*****	80.3	63.8	50.7	40.3	32.0	25.5	20.3	16.1	12.8	10.2	8.1	6.5	5.2	4.1	3.3	2.6	2.1	1.7	1.4	1.1	0.9	0.7	0.6
13.0	*****	*****	93.6	74.4	59.1	47.0	37.3	29.7	23.6	18.8	14.9	11.9	9.5	7.5	6.0	4.8	3.8	3.1	2.5	2.0	1.6	1.3	1.0	0.9	0.7	0.6
14.0	*****	*****	86.7	68.9	54.7	43.5	34.6	27.5	21.9	17.4	13.8	11.0	8.8	7.0	5.6	4.4	3.6	2.8	2.3	1.8	1.5	1.2	1.0	0.8	0.7	0.5
15.0	*****	*****	80.4	63.9	50.7	40.3	32.1	25.5	20.3	16.1	12.8	10.2	8.1	6.5	5.2	4.1	3.3	2.6	2.1	1.7	1.4	1.1	0.9	0.7	0.6	0.5
16.0	*****	93.8	74.5	59.2	47.1	37.4	29.7	23.6	18.8	15.0	11.9	9.5	7.6	6.0	4.8	3.8	3.1	2.5	2.0	1.6	1.3	1.0	0.9	0.7	0.6	0.5
17.0	*****	87.0	69.2	55.0	43.7	34.7	27.6	21.9	17.5	13.9	11.1	8.8	7.0	5.6	4.5	3.6	2.9	2.3	1.8	1.5	1.2	1.0	0.8	0.7	0.5	0.5
18.0	*****	80.8	64.2	51.0	40.6	32.2	25.6	20.4	16.2	12.9	10.3	8.2	6.5	5.2	4.2	3.3	2.7	2.1	1.7	1.4	1.1	0.9	0.8	0.6	0.5	0.4
19.0	94.5	75.1	59.6	47.4	37.7	29.9	23.8	18.9	15.1	12.0	9.5	7.6	6.1	4.8	3.9	3.1	2.5	2.0	1.6	1.3	1.1	0.9	0.7	0.6	0.5	0.4
20.0	87.8	69.7	55.4	44.0	35.0	27.8	22.1	17.6	14.0	11.1	8.9	7.1	5.6	4.5	3.6	2.9	2.3	1.9	1.5	1.2	1.0	0.8	0.7	0.5	0.5	0.4
21.0	81.6	64.9	51.5	41.0	32.6	25.9	20.6	16.4	13.0	10.4	8.3	6.6	5.3	4.2	3.4	2.7	2.2	1.7	1.4	1.1	0.9	0.8	0.6	0.5	0.4	0.4
22.0	75.9	60.3	47.9	38.1	30.3	24.1	19.2	15.2	12.1	9.7	7.7	6.1	4.9	3.9	3.1	2.5	2.0	1.6	1.3	1.1	0.9	0.7	0.6	0.5	0.4	0.3
23.0	70.7	56.2	44.6	35.5	28.2	22.4	17.8	14.2	11.3	9.0	7.2	5.7	4.6	3.6	2.9	2.3	1.9	1.5	1.2	1.0	0.8	0.7	0.6	0.5	0.4	0.3
24.0	65.8	52.3	41.6	33.0	26.3	20.9	16.6	13.2	10.5	8.4	6.7	5.3	4.3	3.4	2.7	2.2	1.8	1.4	1.2	0.9	0.8	0.6	0.5	0.4	0.4	0.3
25.0	61.3	48.7	38.7	30.8	24.5	19.5	15.5	12.3	9.8	7.8	6.2	5.0	4.0	3.2	2.5	2.0	1.6	1.3	1.1	0.9	0.7	0.6	0.5	0.4	0.4	0.3

Table B2.4 Ammonia effluent limits for the City of Boulder based on a 7Q10 chronic design flow and an instream ammonia standard of 0.10 mg/l-N.

DISCHARGER: BOULDER, COLORADO STREAM: BOULDER CREEK
UPSTREAM FLOW IN CFS: 8.4
UPSTREAM AMMONIA IN mg/l: 0.0
UN-IONIZED AMMONIA STANDARD IN mg/l X 10 1.0
DISCHARGE FLOW IN MGD: 15.6

DEGREES CENTIGRADE	pH																									
	6.5	6.6	6.7	6.8	6.9	7.0	7.1	7.2	7.3	7.4	7.5	7.6	7.7	7.8	7.9	8.0	8.1	8.2	8.3	8.4	8.5	8.6	8.7	8.8	8.9	9.0
3.0	*****	*****	*****	*****	*****	*****	*****	80.6	64.0	50.9	40.5	32.2	25.6	20.3	16.2	12.9	10.3	8.2	6.5	5.2	4.2	3.3	2.7	2.2	1.7	1.4
4.0	*****	*****	*****	*****	*****	*****	93.4	74.2	59.0	46.9	37.3	29.6	23.6	18.9	14.9	11.9	9.5	7.5	6.0	4.8	3.8	3.1	2.5	2.0	1.6	1.3
5.0	*****	*****	*****	*****	*****	*****	86.1	68.4	54.4	43.2	34.4	27.3	21.7	17.3	13.8	11.0	8.7	7.0	5.6	4.4	3.6	2.9	2.3	1.9	1.5	1.2
6.0	*****	*****	*****	*****	*****	*****	79.4	63.1	50.2	39.9	31.7	25.2	20.1	16.0	12.7	10.1	8.1	6.4	5.1	4.1	3.3	2.6	2.1	1.7	1.4	1.1
7.0	*****	*****	*****	*****	*****	92.3	73.3	58.3	46.3	36.8	29.3	23.3	18.5	14.7	11.7	9.3	7.5	5.9	4.8	3.8	3.0	2.4	2.0	1.6	1.3	1.1
8.0	*****	*****	*****	*****	*****	85.2	67.7	53.8	42.8	34.0	27.0	21.5	17.1	13.6	10.8	8.6	6.9	5.5	4.4	3.5	2.8	2.3	1.8	1.5	1.2	1.0
9.0	*****	*****	*****	*****	99.1	78.7	62.6	49.7	39.5	31.4	25.0	19.9	15.8	12.6	10.0	8.0	6.4	5.1	4.1	3.3	2.6	2.1	1.7	1.4	1.1	0.9
10.0	*****	*****	*****	*****	91.6	72.8	57.8	46.0	36.5	29.1	23.1	18.4	14.6	11.6	9.3	7.4	5.9	4.7	3.8	3.0	2.4	2.0	1.6	1.3	1.0	0.9
11.0	*****	*****	*****	*****	84.7	67.3	53.5	42.5	33.8	26.9	21.4	17.0	13.5	10.8	8.6	6.9	5.5	4.4	3.5	2.8	2.3	1.8	1.5	1.2	1.0	0.8
12.0	*****	*****	*****	98.7	78.4	62.3	49.5	39.4	31.3	24.9	19.8	15.7	12.5	10.0	8.0	6.4	5.1	4.1	3.3	2.6	2.1	1.7	1.4	1.1	0.9	0.8
13.0	*****	*****	*****	91.4	72.6	57.7	45.9	36.4	29.0	23.0	18.3	14.6	11.6	9.3	7.4	5.9	4.7	3.8	3.0	2.4	2.0	1.6	1.3	1.0	0.9	0.7
14.0	*****	*****	*****	84.6	67.3	53.4	42.5	33.8	26.9	21.4	17.0	13.5	10.8	8.6	6.8	5.5	4.4	3.5	2.8	2.3	1.8	1.5	1.2	1.0	0.8	0.7
15.0	*****	*****	98.7	78.5	62.3	49.5	39.4	31.3	24.9	19.8	15.8	12.5	10.0	8.0	6.4	5.1	4.1	3.3	2.6	2.1	1.7	1.4	1.1	0.9	0.8	0.6
16.0	*****	*****	91.6	72.8	57.8	46.0	36.5	29.0	23.1	18.4	14.6	11.6	9.3	7.4	5.9	4.7	3.8	3.0	2.4	2.0	1.6	1.3	1.0	0.9	0.7	0.6
17.0	*****	*****	85.0	67.5	53.7	42.7	33.9	27.0	21.4	17.1	13.6	10.8	8.6	6.9	5.5	4.4	3.5	2.8	2.3	1.8	1.5	1.2	1.0	0.8	0.7	0.6
18.0	*****	99.3	78.9	62.7	49.8	39.6	31.5	25.0	19.9	15.8	12.6	10.0	8.0	6.4	5.1	4.1	3.3	2.6	2.1	1.7	1.4	1.1	0.9	0.8	0.6	0.5
19.0	*****	92.2	73.3	58.2	46.3	36.8	29.3	23.3	18.5	14.7	11.7	9.3	7.4	5.9	4.7	3.8	3.0	2.4	2.0	1.6	1.3	1.1	0.9	0.7	0.6	0.5
20.0	*****	85.7	68.1	54.1	43.0	34.2	27.2	21.6	17.2	13.7	10.9	8.7	6.9	5.5	4.4	3.5	2.8	2.3	1.8	1.5	1.2	1.0	0.8	0.7	0.6	0.5
21.0	*****	79.7	63.3	50.3	40.0	31.8	25.3	20.1	16.0	12.7	10.1	8.1	6.5	5.2	4.1	3.3	2.7	2.1	1.7	1.4	1.1	0.9	0.8	0.6	0.5	0.5
22.0	93.3	74.1	58.9	46.8	37.2	29.6	23.5	18.7	14.9	11.9	9.4	7.5	6.0	4.8	3.8	3.1	2.5	2.0	1.6	1.3	1.1	0.9	0.7	0.6	0.5	0.4
23.0	86.8	69.0	54.8	43.6	34.6	27.5	21.9	17.4	13.9	11.0	8.8	7.0	5.6	4.5	3.6	2.9	2.3	1.9	1.5	1.2	1.0	0.8	0.7	0.6	0.5	0.4
24.0	80.8	64.2	51.1	40.6	32.3	25.7	20.4	16.2	12.9	10.3	8.2	6.5	5.2	4.2	3.3	2.7	2.2	1.7	1.4	1.2	0.9	0.8	0.6	0.5	0.5	0.4
25.0	75.3	59.9	47.6	37.8	30.1	23.9	19.0	15.1	12.0	9.6	7.7	6.1	4.9	3.9	3.1	2.5	2.0	1.6	1.3	1.1	0.9	0.7	0.6	0.5	0.4	0.4

Table B2.5 Ammonia effluent limits for the City of Boulder based on a 30Q10 chronic design flow and an instream ammonia standard of 0.10 mg/l-N.

DISCHARGER: BOULDER, COLORADO STREAM: BOULDER CREEK
UPSTREAM FLOW IN CFS: 14.0
UPSTREAM AMMONIA IN mg/l: 0.0
UN-IONIZED AMMONIA STANDARD IN mg/l X 10 1.0
DISCHARGE FLOW IN MGD: 15.6

pH

DEGREES CENTIGRADE	6.5	6.6	6.7	6.8	6.9	7.0	7.1	7.2	7.3	7.4	7.5	7.6	7.7	7.8	7.9	8.0	8.1	8.2	8.3	8.4	8.5	8.6	8.7	8.8	8.9	9.0
3.0	*****	*****	*****	*****	*****	*****	*****	94.5	75.1	59.7	47.4	37.7	30.0	23.8	19.0	15.1	12.0	9.6	7.6	6.1	4.9	3.9	3.1	2.5	2.0	1.7
4.0	*****	*****	*****	*****	*****	*****	*****	87.0	69.2	55.0	43.7	34.7	27.6	22.0	17.5	13.9	11.1	8.8	7.1	5.6	4.5	3.6	2.9	2.3	1.9	1.5
5.0	*****	*****	*****	*****	*****	*****	*****	80.2	63.8	50.7	40.3	32.0	25.5	20.3	16.1	12.8	10.2	8.2	6.5	5.2	4.2	3.3	2.7	2.2	1.8	1.4
6.0	*****	*****	*****	*****	*****	*****	93.1	74.0	58.8	46.7	37.2	29.6	23.5	18.7	14.9	11.9	9.5	7.5	6.0	4.8	3.9	3.1	2.5	2.0	1.6	1.3
7.0	*****	*****	*****	*****	*****	*****	85.9	68.3	54.3	43.1	34.3	27.3	21.7	17.3	13.8	11.0	8.7	7.0	5.6	4.5	3.6	2.9	2.3	1.9	1.5	1.2
8.0	*****	*****	*****	*****	*****	99.9	79.4	63.1	50.1	39.9	31.7	25.2	20.1	16.0	12.7	10.1	8.1	6.4	5.2	4.1	3.3	2.7	2.1	1.7	1.4	1.2
9.0	*****	*****	*****	*****	*****	92.3	73.3	58.3	46.3	36.8	29.3	23.3	18.5	14.8	11.8	9.4	7.5	6.0	4.8	3.8	3.1	2.5	2.0	1.6	1.3	1.1
10.0	*****	*****	*****	*****	*****	85.3	67.9	53.9	42.8	34.1	27.1	21.5	17.1	13.7	10.9	8.7	6.9	5.5	4.4	3.5	2.9	2.3	1.9	1.5	1.2	1.0
11.0	*****	*****	*****	*****	99.3	78.9	62.7	49.8	39.6	31.5	25.1	19.9	15.9	12.6	10.1	8.0	6.4	5.1	4.1	3.3	2.6	2.1	1.7	1.4	1.1	0.9
12.0	*****	*****	*****	*****	91.7	73.0	58.0	46.1	36.7	29.2	23.2	18.5	14.7	11.7	9.3	7.4	5.9	4.8	3.8	3.1	2.5	2.0	1.6	1.3	1.1	0.9
13.0	*****	*****	*****	*****	85.1	67.6	53.7	42.7	34.0	27.0	21.5	17.1	13.6	10.8	8.7	6.9	5.5	4.4	3.5	2.8	2.3	1.9	1.5	1.2	1.0	0.8
14.0	*****	*****	*****	99.2	78.8	62.6	49.8	39.6	31.5	25.0	19.9	15.9	12.6	10.1	8.0	6.4	5.1	4.1	3.3	2.6	2.1	1.7	1.4	1.1	0.9	0.8
15.0	*****	*****	*****	92.0	73.1	58.1	46.2	36.7	29.2	23.2	18.5	14.7	11.7	9.3	7.4	6.0	4.8	3.8	3.1	2.5	2.0	1.6	1.3	1.1	0.9	0.7
16.0	*****	*****	*****	85.3	67.8	53.9	42.8	34.0	27.1	21.5	17.1	13.6	10.9	8.7	6.9	5.5	4.4	3.5	2.8	2.3	1.9	1.5	1.2	1.0	0.8	0.7
17.0	*****	*****	99.6	79.1	62.9	50.0	39.7	31.6	25.1	20.0	15.9	12.7	10.1	8.1	6.4	5.1	4.1	3.3	2.7	2.1	1.7	1.4	1.2	0.9	0.8	0.7
18.0	*****	*****	92.5	73.5	58.4	46.4	36.9	29.3	23.3	18.6	14.8	11.5	9.4	7.5	6.0	4.8	3.8	3.1	2.5	2.0	1.6	1.3	1.1	0.9	0.7	0.6
19.0	*****	*****	85.9	68.3	54.2	43.1	34.3	27.3	21.7	17.3	13.7	11.0	8.7	7.0	5.6	4.5	3.6	2.9	2.3	1.9	1.5	1.2	1.0	0.8	0.7	0.6
20.0	*****	*****	79.8	63.4	50.4	40.1	31.9	25.3	20.2	16.1	12.8	10.2	8.1	6.5	5.2	4.2	3.3	2.7	2.2	1.7	1.4	1.2	1.0	0.8	0.7	0.6
21.0	*****	93.4	74.2	59.0	46.9	37.3	29.6	23.6	18.8	14.9	11.9	9.5	7.6	6.0	4.8	3.9	3.1	2.5	2.0	1.6	1.3	1.1	0.9	0.7	0.6	0.5
22.0	*****	86.9	69.0	54.9	43.6	34.7	27.6	21.9	17.5	13.9	11.1	8.8	7.0	5.6	4.5	3.6	2.9	2.3	1.9	1.5	1.2	1.0	0.8	0.7	0.6	0.5
23.0	*****	80.9	64.3	51.1	40.6	32.3	25.7	20.4	16.3	12.9	10.3	8.2	6.6	5.3	4.2	3.4	2.7	2.2	1.8	1.4	1.2	1.0	0.8	0.7	0.6	0.5
24.0	94.8	75.3	59.8	47.6	37.8	30.1	23.9	19.0	15.2	12.1	9.6	7.7	6.1	4.9	3.9	3.1	2.5	2.0	1.7	1.3	1.1	0.9	0.8	0.6	0.5	0.5
25.0	88.3	70.2	55.8	44.3	35.2	28.0	22.3	17.7	14.1	11.3	9.0	7.2	5.7	4.6	3.7	2.9	2.4	1.9	1.6	1.3	1.0	0.9	0.7	0.6	0.5	0.4

Table B2.6 Ammonia effluent limits for the City of Boulder based on a 30Q3 chronic design flow and an instream ammonia standard of 0.10 mg/l-N.

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DISCHARGER:   BOULDER, COLORADO   STREAM:   BOULDER CREEK
UPSTREAM FLOW IN CFS:                       20.0
UPSTREAM AMMONIA IN mg/l:                    0.0
UN-IONIZED AMMONIA STANDARD IN mg/l x 10     1.0
DISCHARGE FLOW IN MGD:                      15.5

                                                                  pH
          6.5  6.6  6.7  6.8  6.9  7.0  7.1  7.2  7.3  7.4  7.5  7.6  7.7  7.8  7.9  8.0  8.1  8.2  8.3  8.4  8.5  8.6  8.7  8.8  8.9  9.0
DEGREES
CENTIGRADE
   3.0    ****************************************85.9 69.0 54.9 43.6 34.7 27.6 22.0 17.5 13.9 11.1  8.9  7.1  5.7  4.5  3.6  2.9  2.4  1.9
   4.0    ****************************************80.0 63.5 50.6 40.2 32.0 25.4 20.2 16.1 12.8 10.2  8.2  6.5  5.2  4.2  3.4  2.7  2.2  1.8
   5.0    ***********************************92.5 73.8 58.6 46.6 37.1 29.5 23.5 18.7 14.9 11.6  9.4  7.5  6.0  4.8  3.9  3.1  2.5  2.0  1.7
   6.0    ***********************************85.6 68.1 54.1 43.0 34.2 27.2 21.6 17.2 13.7 10.9  8.7  7.0  5.6  4.5  3.6  2.9  2.3  1.9  1.5
   7.0    ******************************99.5 79.0 62.8 49.9 39.7 31.6 25.1 20.0 15.9 12.7 10.1  8.1  6.4  5.2  4.1  3.3  2.7  2.2  1.8  1.4
   8.0    ******************************91.8 73.0 58.0 46.1 36.7 29.2 23.2 18.5 14.7 11.7  9.3  7.5  6.0  4.8  3.8  3.1  2.5  2.0  1.6  1.3
   9.0    ******************************84.9 67.4 53.6 42.6 33.9 27.0 21.5 17.1 13.6 10.8  8.7  6.9  5.5  4.4  3.6  2.9  2.3  1.9  1.5  1.2
  10.0    *************************98.7 78.5 62.4 49.6 39.4 31.3 24.9 19.8 15.8 12.6 10.0  8.0  6.4  5.1  4.1  3.3  2.7  2.1  1.7  1.4  1.2
  11.0    *************************91.3 72.6 57.7 45.9 36.5 29.0 23.1 18.4 14.6 11.7  9.3  7.4  5.9  4.8  3.8  3.1  2.5  2.0  1.6  1.3  1.1
  12.0    *************************84.5 67.2 53.4 42.4 33.8 26.8 21.4 17.0 13.5 10.8  8.6  6.9  5.5  4.4  3.5  2.8  2.3  1.9  1.5  1.2  1.0
  13.0    ********************98.5 78.3 62.2 49.4 39.3 31.3 24.9 19.8 15.8 12.6 10.0  8.0  6.4  5.1  4.1  3.3  2.7  2.1  1.7  1.4  1.2  1.0
  14.0    ********************91.2 72.5 57.6 45.8 36.4 29.0 23.1 18.4 14.6 11.6  9.3  7.4  5.9  4.7  3.8  3.1  2.5  2.0  1.6  1.3  1.1  0.9
  15.0    ********************84.6 67.2 53.4 42.5 33.8 26.9 21.4 17.0 13.6 10.8  8.6  6.9  5.5  4.4  3.5  2.9  2.3  1.9  1.5  1.2  1.0  0.9
  16.0    ***************98.7 78.4 62.3 49.6 39.4 31.3 24.9 19.8 15.8 12.6 10.0  8.0  6.4  5.1  4.1  3.3  2.7  2.1  1.7  1.4  1.2  1.0  0.8
  17.0    ***************91.6 72.8 57.9 46.0 36.6 29.1 23.1 18.4 14.7 11.7  9.3  7.4  6.0  4.8  3.8  3.1  2.5  2.0  1.6  1.3  1.1  0.9  0.8
  18.0    ***************85.0 67.6 53.7 42.7 34.0 27.0 21.5 17.1 13.6 10.9  8.7  6.9  5.5  4.4  3.6  2.9  2.3  1.9  1.5  1.3  1.0  0.9  0.7
  19.0    **********99.4 79.0 62.8 49.9 39.7 31.6 25.1 20.0 15.9 12.7 10.1  8.1  6.4  5.2  4.1  3.3  2.7  2.2  1.8  1.4  1.2  1.0  0.8  0.7
  20.0    **********92.4 73.4 58.4 46.4 36.9 29.3 23.3 18.6 14.8 11.8  9.4  7.5  6.0  4.8  3.9  3.1  2.5  2.0  1.6  1.3  1.1  0.9  0.8  0.6
  21.0    **********85.9 68.3 54.3 43.1 34.3 27.3 21.7 17.3 13.8 11.0  8.8  7.0  5.6  4.5  3.6  2.9  2.3  1.9  1.5  1.3  1.0  0.9  0.7  0.6
  22.0    **********77.9 63.5 50.5 40.1 31.9 25.4 20.2 16.1 12.8 10.2  8.2  6.5  5.2  4.2  3.4  2.7  2.2  1.8  1.4  1.2  1.0  0.8  0.7  0.6
  23.0    *****93.6 74.4 59.1 47.0 37.4 29.7 23.6 18.8 15.0 11.9  9.5  7.6  6.1  4.9  3.9  3.1  2.5  2.0  1.7  1.4  1.1  0.9  0.8  0.7  0.6
  24.0    *****87.1 69.3 55.1 43.8 34.8 27.7 22.0 17.5 14.0 11.1  8.9  7.1  5.7  4.5  3.6  2.9  2.4  1.9  1.6  1.3  1.1  0.9  0.7  0.6  0.5
  25.0    *****81.2 64.5 51.3 40.8 32.4 25.8 20.5 16.3 13.0 10.4  8.3  6.6  5.3  4.2  3.4  2.7  2.2  1.8  1.5  1.2  1.0  0.8  0.7  0.6  0.5
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Table B2.7 Ammonia effluent limits for the City of Boulder based on a 1Q10 acute design flow and an instream ammonia standard of 0.20 mg/l-N.

DISCHARGER: BOULDER, COLORADO STREAM: BOULDER CREEK
UPSTREAM FLOW IN CFS: 5.1
UPSTREAM AMMONIA IN mg/l: 0.0
UN-IONIZED AMMONIA STANDARD IN mg/l X 10 2.0
DISCHARGE FLOW IN MGD: 15.6

pH

DEGREES CENTIGRADE	6.5	6.6	6.7	6.8	6.9	7.0	7.1	7.2	7.3	7.4	7.5	7.6	7.7	7.8	7.9	8.0	8.1	8.2	8.3	8.4	8.5	8.6	8.7	8.8	8.9	9.0
3.0	*****	*****	*****	*****	*****	*****	*****	*****	*****	91.5	72.7	57.8	46.0	36.6	29.1	23.2	18.4	14.7	11.7	9.4	7.5	6.0	4.8	3.9	3.1	2.5
4.0	*****	*****	*****	*****	*****	*****	*****	*****	*****	84.3	67.0	53.3	42.4	33.7	26.8	21.4	17.0	13.6	10.8	8.6	6.9	5.5	4.5	3.6	2.9	2.4
5.0	*****	*****	*****	*****	*****	*****	*****	*****	*****	97.7	77.7	61.8	49.1	39.1	31.1	24.7	19.7	15.7	12.5	10.0	8.0	6.4	5.1	4.1	3.3	2.7	2.2
6.0	*****	*****	*****	*****	*****	*****	*****	*****	90.2	71.7	57.0	45.3	36.0	28.7	22.8	18.2	14.5	11.6	9.2	7.4	5.9	4.7	3.8	3.1	2.5	2.0
7.0	*****	*****	*****	*****	*****	*****	*****	*****	83.2	66.2	52.6	41.8	33.3	26.5	21.1	16.8	13.4	10.7	8.5	6.8	5.5	4.4	3.5	2.9	2.3	1.9
8.0	*****	*****	*****	*****	*****	*****	*****	96.7	76.9	61.7	48.6	38.6	30.7	24.5	19.5	15.5	12.4	9.9	7.9	6.3	5.1	4.1	3.3	2.7	2.2	1.8
9.0	*****	*****	*****	*****	*****	*****	*****	89.3	71.0	56.5	44.9	35.7	28.4	22.6	18.0	14.4	11.5	9.2	7.3	5.9	4.7	3.8	3.1	2.5	2.0	1.7
10.0	*****	*****	*****	*****	*****	*****	*****	82.6	65.7	52.2	41.5	33.0	26.3	20.9	16.7	13.3	10.6	8.5	6.8	5.4	4.4	3.5	2.6	2.3	1.9	1.5
11.0	*****	*****	*****	*****	*****	*****	96.1	76.4	60.7	48.3	38.4	30.6	24.3	19.4	15.4	12.3	9.8	7.9	6.3	5.0	4.1	3.3	2.7	2.2	1.8	1.4
12.0	*****	*****	*****	*****	*****	*****	89.0	70.7	56.2	44.7	35.6	28.3	22.5	17.9	14.3	11.4	9.1	7.3	5.8	4.7	3.8	3.0	2.5	2.0	1.6	1.4
13.0	*****	*****	*****	*****	*****	*****	82.4	65.5	52.1	41.4	32.9	26.2	20.9	16.6	13.3	10.6	8.5	6.8	5.4	4.4	3.5	2.8	2.3	1.9	1.5	1.3
14.0	*****	*****	*****	*****	*****	96.1	76.3	60.7	48.3	38.4	30.5	24.3	19.4	15.4	12.3	9.8	7.9	6.3	5.0	4.1	3.3	2.6	2.2	1.8	1.4	1.2
15.0	*****	*****	*****	*****	*****	89.0	70.8	56.3	44.7	35.6	28.3	22.5	18.0	14.3	11.4	9.1	7.3	5.8	4.7	3.8	3.1	2.5	2.0	1.6	1.4	1.1
16.0	*****	*****	*****	*****	*****	82.6	65.7	52.2	41.5	33.0	26.3	20.9	16.7	13.3	10.6	8.5	6.8	5.4	4.4	3.5	2.8	2.3	1.9	1.5	1.3	1.1
17.0	*****	*****	*****	*****	96.4	76.6	60.9	48.5	38.5	30.7	24.4	19.4	15.5	12.4	9.9	7.9	6.3	5.1	4.1	3.3	2.7	2.2	1.8	1.5	1.2	1.0
18.0	*****	*****	*****	*****	89.5	71.2	56.6	45.0	35.8	28.5	22.7	18.1	14.4	11.5	9.2	7.3	5.9	4.7	3.8	3.1	2.5	2.0	1.7	1.4	1.1	1.0
19.0	*****	*****	*****	*****	83.2	66.1	52.6	41.8	33.3	26.5	21.1	16.8	13.4	10.7	8.5	6.8	5.5	4.4	3.5	2.9	2.3	1.9	1.6	1.3	1.1	0.9
20.0	*****	*****	*****	97.3	77.3	61.5	48.9	38.9	30.9	24.6	19.6	15.6	12.5	9.9	7.9	6.4	5.1	4.1	3.3	2.7	2.2	1.8	1.5	1.2	1.0	0.9
21.0	*****	*****	*****	90.4	71.9	57.2	45.4	36.1	28.8	22.9	18.2	14.5	11.6	9.3	7.4	5.9	4.8	3.8	3.1	2.5	2.0	1.7	1.4	1.1	1.0	0.8
22.0	*****	*****	*****	84.1	66.9	53.2	42.3	33.6	26.8	21.3	17.0	13.5	10.8	8.6	6.9	5.5	4.4	3.6	2.9	2.3	1.9	1.6	1.3	1.1	0.9	0.8
23.0	*****	*****	98.5	78.3	62.3	49.5	39.4	31.3	24.9	19.9	15.8	12.6	10.1	8.0	6.4	5.2	4.2	3.4	2.7	2.2	1.8	1.5	1.2	1.0	0.9	0.7
24.0	*****	*****	91.8	72.9	58.0	46.1	36.7	29.2	23.2	18.5	14.7	11.8	9.4	7.5	6.0	4.8	3.9	3.1	2.5	2.1	1.7	1.4	1.2	1.0	0.8	0.7
25.0	*****	*****	85.5	68.0	54.0	43.0	34.2	27.2	21.7	17.3	13.8	11.0	8.8	7.0	5.6	4.5	3.6	2.9	2.4	1.9	1.6	1.3	1.1	0.9	0.8	0.7

Table B2.8 Ammonia effluent limits for theCity of Boulder based on a 1Q10 acute design flow and an instream ammonia standard of 0.20 mg/l-N.

DISCHARGER: BOULDER, COLORADO STREAM: BOULDER CREEK
UPSTREAM FLOW IN CFS: 9.6
UPSTREAM AMMONIA IN mg/l: 0.0
UN-IONIZED AMMONIA STANDARD IN mg/l * 10 2.0
DISCHARGE FLOW IN MGD: 15.6

DEGREES CENTIGRADE	pH 6.5	6.6	6.7	6.8	6.9	7.0	7.1	7.2	7.3	7.4	7.5	7.6	7.7	7.8	7.9	8.0	8.1	8.2	8.3	8.4	8.5	8.6	8.7	8.8	8.9	9.0
3.0	*****	*****	*****	*****	*****	*****	*****	*****	*****	*****	83.9	66.7	53.0	42.2	33.6	26.7	21.3	17.0	13.5	10.8	8.6	6.9	5.6	4.5	3.6	2.9
4.0	*****	*****	*****	*****	*****	*****	*****	*****	*****	97.2	77.3	61.5	48.9	38.9	30.9	24.6	19.6	15.6	12.5	10.0	8.0	6.4	5.1	4.1	3.3	2.7
5.0	*****	*****	*****	*****	*****	*****	*****	*****	*****	89.7	71.3	56.7	45.1	35.9	28.5	22.7	18.1	14.4	11.5	9.2	7.4	5.9	4.8	3.8	3.1	2.5
6.0	*****	*****	*****	*****	*****	*****	*****	*****	*****	82.7	65.8	52.3	41.6	33.1	26.3	21.0	16.7	13.3	10.7	8.5	6.8	5.5	4.4	3.6	2.9	2.3
7.0	*****	*****	*****	*****	*****	*****	*****	*****	96.0	76.3	60.7	48.3	38.4	30.6	24.3	19.4	15.5	12.3	9.9	7.9	6.3	5.1	4.1	3.3	2.7	2.2
8.0	*****	*****	*****	*****	*****	*****	*****	*****	88.7	70.5	56.1	44.6	35.5	28.2	22.5	17.9	14.3	11.4	9.1	7.3	5.9	4.7	3.8	3.1	2.5	2.0
9.0	*****	*****	*****	*****	*****	*****	*****	*****	82.0	65.2	51.8	41.2	32.8	26.1	20.8	16.6	13.2	10.6	8.4	6.8	5.4	4.4	3.5	2.9	2.3	1.9
10.0	*****	*****	*****	*****	*****	*****	*****	95.3	75.8	60.2	47.9	38.1	30.3	24.2	19.2	15.3	12.2	9.8	7.8	6.3	5.0	4.1	3.3	2.7	2.2	1.8
11.0	*****	*****	*****	*****	*****	*****	*****	88.2	70.1	55.7	44.3	35.3	28.1	22.4	17.8	14.2	11.3	9.1	7.3	5.8	4.7	3.8	3.1	2.5	2.0	1.7
12.0	*****	*****	*****	*****	*****	*****	*****	81.6	64.9	51.6	41.0	32.7	26.0	20.7	16.5	13.2	10.5	8.4	6.7	5.4	4.4	3.5	2.9	2.3	1.9	1.6
13.0	*****	*****	*****	*****	*****	*****	95.1	75.6	60.1	47.8	38.0	30.3	24.1	19.2	15.3	12.2	9.8	7.8	6.3	5.0	4.1	3.3	2.7	2.2	1.8	1.5
14.0	*****	*****	*****	*****	*****	*****	88.1	70.0	55.7	44.3	35.2	28.1	22.3	17.8	14.2	11.3	9.1	7.3	5.8	4.7	3.8	3.1	2.5	2.0	1.7	1.4
15.0	*****	*****	*****	*****	*****	*****	81.7	64.9	51.6	41.1	32.7	26.0	20.7	16.5	13.2	10.5	8.4	6.7	5.4	4.4	3.5	2.9	2.3	1.9	1.6	1.3
16.0	*****	*****	*****	*****	*****	95.3	75.8	60.2	47.9	38.1	30.3	24.1	19.2	15.3	12.2	9.8	7.8	6.3	5.0	4.1	3.3	2.7	2.2	1.8	1.5	1.2
17.0	*****	*****	*****	*****	*****	88.4	70.3	55.9	44.5	35.4	28.2	22.4	17.9	14.3	11.4	9.1	7.3	5.8	4.7	3.8	3.1	2.5	2.0	1.7	1.4	1.2
18.0	*****	*****	*****	*****	*****	82.1	65.3	51.9	41.3	32.9	26.2	20.8	16.6	13.3	10.6	8.5	6.8	5.4	4.4	3.5	2.9	2.3	1.9	1.6	1.3	1.1
19.0	*****	*****	*****	*****	96.0	76.3	60.7	48.2	38.4	30.5	24.3	19.4	15.4	12.3	9.8	7.9	6.3	5.1	4.1	3.3	2.7	2.2	1.8	1.5	1.2	1.0
20.0	*****	*****	*****	*****	89.2	70.9	56.4	44.8	35.7	28.4	22.6	18.0	14.4	11.5	9.2	7.3	5.9	4.7	3.8	3.1	2.5	2.1	1.7	1.4	1.2	1.0
21.0	*****	*****	*****	*****	83.0	65.9	52.4	41.7	33.2	26.4	21.0	16.8	13.4	10.7	8.5	6.8	5.5	4.4	3.6	2.9	2.4	1.9	1.6	1.3	1.1	0.9
22.0	*****	*****	*****	97.1	77.2	61.4	48.8	38.8	30.9	24.6	19.6	15.6	12.5	10.0	8.0	6.4	5.1	4.1	3.3	2.7	2.2	1.8	1.5	1.2	1.0	0.9
23.0	*****	*****	*****	90.4	71.8	57.1	45.4	36.1	28.8	22.9	18.3	14.6	11.6	9.3	7.4	6.0	4.8	3.9	3.1	2.5	2.1	1.7	1.4	1.2	1.0	0.8
24.0	*****	*****	*****	84.2	66.9	53.2	42.3	33.7	26.8	21.3	17.0	13.6	10.8	8.7	6.9	5.6	4.5	3.6	2.9	2.4	2.0	1.6	1.3	1.1	0.9	0.8
25.0	*****	*****	98.6	78.4	62.3	49.6	39.4	31.4	25.0	19.9	15.9	12.7	10.1	8.1	6.5	5.2	4.2	3.4	2.8	2.2	1.8	1.5	1.3	1.1	0.9	0.8

Table B3.1 Ammonia effluent limits for the City of Longmont based on a 7Q10 chronic design flow and an instream ammonia standard of 0.06 mg/l-N.

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DISCHARGER: LONGMONT             STREAM: SAINT VRAIN
UPSTREAM FLOW IN CFS:                      12.0
UPSTREAM AMMONIA IN mg/l:                   0.0
UN-IONIZED AMMONIA STANDARD IN mg/l X 10    0.6
DISCHARGE FLOW IN MGD:                     11.6

                                                            pH
         6.5  6.6  6.7  6.8  6.9  7.0  7.1  7.2  7.3  7.4  7.5  7.6  7.7  7.8  7.9  8.0  8.1  8.2  8.3  8.4  8.5  8.6  8.7  8.8  8.9  9.0
DEGREES
CENTIGRADE
  3.0    *************************95.0 75.5 60.0 47.6 37.9 30.1 23.9 19.0 15.1 12.0  9.6  7.6  6.1  4.9  3.9  3.1  2.5  2.0  1.6  1.3  1.0
  4.0    *************************87.5 69.5 55.2 43.9 34.9 27.7 22.1 17.5 14.0 11.1  8.8  7.0  5.6  4.5  3.6  2.9  2.3  1.8  1.5  1.2  1.0
  5.0    *************************80.6 64.1 50.9 40.5 32.2 25.6 20.3 16.2 12.9 10.2  8.2  6.5  5.2  4.1  3.3  2.6  2.1  1.7  1.4  1.1  0.9
  6.0    ********************93.6 74.4 59.1 47.0 37.3 29.7 23.6 18.8 14.9 11.9  9.5  7.5  6.0  4.8  3.8  3.1  2.4  2.0  1.6  1.3  1.0  0.8
  7.0    ********************86.4 68.6 54.5 43.3 34.5 27.4 21.8 17.3 13.8 11.0  8.7  7.0  5.5  4.4  3.5  2.8  2.3  1.8  1.5  1.2  1.0  0.8
  8.0    ********************79.8 63.4 50.4 40.0 31.8 25.3 20.1 16.0 12.7 10.1  8.1  6.4  5.1  4.1  3.3  2.6  2.1  1.7  1.4  1.1  0.9  0.7
  9.0    ***************92.8 73.7 58.6 46.5 37.0 29.4 23.4 18.6 14.8 11.8  9.4  7.5  5.9  4.7  3.8  3.0  2.4  1.9  1.6  1.3  1.0  0.8  0.7
 10.0    ***************85.7 68.1 54.1 43.0 34.2 27.2 21.6 17.2 13.7 10.9  8.7  6.9  5.5  4.4  3.5  2.8  2.3  1.8  1.5  1.2  1.0  0.8  0.6
 11.0    **********99.8 79.3 63.0 50.1 39.8 31.6 25.1 20.0 15.9 12.7 10.1  8.0  6.4  5.1  4.1  3.3  2.6  2.1  1.7  1.4  1.1  0.9  0.7  0.6
 12.0    **********92.4 73.4 58.3 46.3 36.8 29.3 23.3 18.5 14.7 11.7  9.3  7.4  5.9  4.7  3.8  3.0  2.4  1.9  1.6  1.3  1.0  0.8  0.7  0.6
 13.0    **********85.5 68.0 54.0 42.9 34.1 27.1 21.6 17.1 13.6 10.9  8.6  6.9  5.5  4.4  3.5  2.8  2.2  1.8  1.5  1.2  1.0  0.8  0.6  0.5
 14.0    *****99.7 79.2 63.0 50.0 39.8 31.6 25.1 20.0 15.9 12.6 10.1  8.0  6.4  5.1  4.1  3.3  2.6  2.1  1.7  1.4  1.1  0.9  0.7  0.6  0.5
 15.0    *****92.4 73.5 58.4 46.4 36.9 29.3 23.3 18.5 14.7 11.7  9.3  7.4  5.9  4.7  3.8  3.0  2.4  1.9  1.6  1.3  1.0  0.8  0.7  0.6  0.5
 16.0    *****85.7 68.1 54.1 43.0 34.2 27.2 21.6 17.2 13.7 10.9  8.7  6.9  5.5  4.4  3.5  2.8  2.3  1.8  1.5  1.2  1.0  0.8  0.6  0.5  0.4
 17.0    *****79.6 63.2 50.2 39.9 31.7 25.2 20.1 16.0 12.7 10.1  8.0  6.4  5.1  4.1  3.3  2.6  2.1  1.7  1.4  1.1  0.9  0.7  0.6  0.5  0.4
 18.0    93.0 73.9 58.7 46.6 37.1 29.5 23.4 18.6 14.8 11.8  9.4  7.5  6.0  4.8  3.8  3.0  2.4  2.0  1.6  1.3  1.0  0.8  0.7  0.6  0.5  0.4
 19.0    86.3 68.6 54.5 43.3 34.4 27.4 21.8 17.3 13.8 11.0  8.7  7.0  5.5  4.4  3.5  2.8  2.3  1.8  1.5  1.2  1.0  0.8  0.6  0.5  0.4  0.4
 20.0    80.2 63.8 50.7 40.3 32.0 25.4 20.2 16.1 12.8 10.2  8.1  6.5  5.2  4.1  3.3  2.6  2.1  1.7  1.4  1.1  0.9  0.7  0.6  0.5  0.4  0.4
 21.0    74.6 59.3 47.1 37.4 29.8 23.7 18.8 15.0 11.9  9.5  7.6  6.0  4.8  3.8  3.1  2.5  2.0  1.6  1.3  1.0  0.8  0.7  0.6  0.5  0.4  0.3
 22.0    69.4 55.1 43.8 34.8 27.7 22.0 17.5 13.9 11.1  8.8  7.0  5.6  4.5  3.6  2.9  2.3  1.8  1.5  1.2  1.0  0.8  0.7  0.5  0.4  0.4  0.3
 23.0    64.6 51.3 40.8 32.4 25.8 20.5 16.3 13.0 10.3  8.2  6.5  5.2  4.2  3.3  2.7  2.1  1.7  1.4  1.1  0.9  0.7  0.6  0.5  0.4  0.4  0.3
 24.0    60.1 47.8 38.0 30.2 24.0 19.1 15.2 12.1  9.6  7.7  6.1  4.9  3.9  3.1  2.5  2.0  1.6  1.3  1.1  0.9  0.7  0.6  0.5  0.4  0.3  0.3
 25.0    55.0 44.5 35.4 28.1 22.4 17.8 14.1 11.3  9.0  7.1  5.7  4.5  3.6  2.9  2.3  1.9  1.5  1.2  1.0  0.8  0.7  0.5  0.5  0.4  0.3  0.3
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Table B3.2 Ammonia effluent limits for the City of Longmont based on a 30Q10 chronic design flow and an instream ammonia standard of 0.06 mg/l-N.

DISCHARGER: LONGMONT STREAM: SAINT VRAIN

UPSTREAM FLOW IN CFS:	18.0
UPSTREAM AMMONIA IN mg/l:	0.0
UN-IONIZED AMMONIA STANDARD IN mg/l X 10	0.6
DISCHARGE FLOW IN MGD:	11.6

	pH																									
DEGREES CENTIGRADE	6.5	6.6	6.7	6.8	6.9	7.0	7.1	7.2	7.3	7.4	7.5	7.6	7.7	7.8	7.9	8.0	8.1	8.2	8.3	8.4	8.5	8.6	8.7	8.8	8.9	9.0
3.0	*****	*****	*****	*****	*****	*****	90.6	72.0	57.2	45.5	36.1	28.7	22.9	18.2	14.5	11.5	9.2	7.3	5.8	4.7	3.7	3.0	2.4	1.9	1.6	1.3
4.0	*****	*****	*****	*****	*****	*****	83.5	66.3	52.7	41.9	33.3	26.5	21.1	16.8	13.3	10.6	8.5	6.7	5.4	4.3	3.4	2.8	2.2	1.8	1.4	1.2
5.0	*****	*****	*****	*****	*****	95.8	77.0	61.1	48.6	38.6	30.7	24.4	19.4	15.5	12.3	9.8	7.8	6.2	5.0	4.0	3.2	2.6	2.1	1.7	1.3	1.1
6.0	*****	*****	*****	*****	*****	89.3	71.0	56.4	44.8	35.6	28.3	22.5	17.9	14.3	11.4	9.0	7.2	5.7	4.6	3.7	2.9	2.4	1.9	1.5	1.2	1.0
7.0	*****	*****	*****	*****	*****	82.4	65.5	52.1	41.4	32.9	26.2	20.8	16.5	13.2	10.5	8.4	6.7	5.3	4.2	3.4	2.7	2.2	1.8	1.4	1.2	0.9
8.0	*****	*****	*****	*****	95.8	76.1	60.5	48.1	38.2	30.4	24.2	19.2	15.3	12.2	9.7	7.7	6.2	4.9	3.9	3.1	2.5	2.0	1.6	1.3	1.1	0.9
9.0	*****	*****	*****	*****	88.5	70.3	55.9	44.4	35.3	28.1	22.3	17.8	14.1	11.2	9.0	7.1	5.7	4.6	3.6	2.9	2.3	1.9	1.5	1.2	1.0	0.8
10.0	*****	*****	*****	*****	81.8	65.0	51.7	41.1	32.6	26.0	20.6	16.4	13.1	10.4	8.3	6.6	5.3	4.2	3.4	2.7	2.2	1.8	1.4	1.1	0.9	0.8
11.0	*****	*****	*****	95.2	75.7	60.1	47.8	38.0	30.2	24.0	19.1	15.2	12.1	9.6	7.7	6.1	4.9	3.9	3.1	2.5	2.0	1.6	1.3	1.1	0.9	0.7
12.0	*****	*****	*****	88.1	70.0	55.7	44.2	35.2	28.0	22.2	17.7	14.1	11.2	8.9	7.1	5.7	4.5	3.6	2.9	2.3	1.9	1.5	1.2	1.0	0.8	0.7
13.0	*****	*****	*****	81.6	64.9	51.5	41.0	32.6	25.9	20.6	16.4	13.0	10.4	8.3	6.6	5.3	4.2	3.4	2.7	2.2	1.7	1.4	1.1	0.9	0.8	0.6
14.0	*****	*****	95.2	75.6	60.1	47.8	38.0	30.2	24.0	19.1	15.2	12.1	9.6	7.7	6.1	4.9	3.9	3.1	2.5	2.0	1.6	1.3	1.1	0.9	0.7	0.6
15.0	*****	*****	88.2	70.1	55.7	44.3	35.2	28.0	22.2	17.7	14.1	11.2	8.9	7.1	5.7	4.5	3.6	2.9	2.3	1.9	1.5	1.2	1.0	0.8	0.7	0.6
16.0	*****	*****	81.8	65.0	51.7	41.1	32.6	26.0	20.6	16.4	13.1	10.4	8.3	6.6	5.3	4.2	3.4	2.7	2.2	1.8	1.4	1.1	0.9	0.8	0.6	0.5
17.0	*****	95.5	75.9	60.3	47.9	38.1	30.3	24.1	19.2	15.2	12.1	9.7	7.7	6.1	4.9	3.9	3.1	2.5	2.0	1.6	1.3	1.1	0.9	0.7	0.6	0.5
18.0	*****	88.7	70.5	56.0	44.5	35.4	28.1	22.4	17.8	14.2	11.3	9.0	7.2	5.7	4.6	3.6	2.9	2.3	1.9	1.5	1.2	1.0	0.8	0.7	0.6	0.5
19.0	*****	82.4	65.5	52.0	41.4	32.9	26.1	20.8	16.5	13.2	10.5	8.3	6.7	5.3	4.2	3.4	2.7	2.2	1.8	1.4	1.2	0.9	0.8	0.6	0.5	0.4
20.0	96.4	75.6	60.8	48.4	38.4	30.6	24.3	19.3	15.4	12.2	9.7	7.8	6.2	4.9	4.0	3.2	2.5	2.0	1.6	1.3	1.1	0.9	0.7	0.6	0.5	0.4
21.0	89.6	71.2	56.6	45.0	35.7	28.4	22.6	18.0	14.3	11.4	9.1	7.2	5.8	4.6	3.7	2.9	2.4	1.9	1.5	1.2	1.0	0.8	0.7	0.6	0.5	0.4
22.0	83.3	66.2	52.6	41.8	33.3	26.4	21.0	16.7	13.3	10.6	8.4	6.7	5.4	4.3	3.4	2.8	2.2	1.8	1.4	1.2	1.0	0.8	0.6	0.5	0.5	0.4
23.0	77.6	61.6	49.0	38.9	31.0	24.6	19.6	15.6	12.4	9.9	7.9	6.3	5.0	4.0	3.2	2.6	2.1	1.7	1.3	1.1	0.9	0.7	0.6	0.5	0.4	0.4
24.0	72.2	57.4	45.6	36.3	28.8	22.9	18.2	14.5	11.5	9.2	7.3	5.8	4.7	3.7	3.0	2.4	1.9	1.6	1.3	1.0	0.8	0.7	0.6	0.5	0.4	0.3
25.0	67.3	53.5	42.5	33.8	26.9	21.4	17.0	13.5	10.8	8.6	6.8	5.5	4.4	3.5	2.8	2.2	1.8	1.5	1.2	1.0	0.8	0.7	0.5	0.5	0.4	0.3

Table B3.3 Ammonia effluent limits for the City of Longmont based on a 30Q3 chronic design flow and an instream ammonia standard of 0.06 mg/l-N.

```
DISCHARGER: LONGMONT            STREAM: SAINT VRAIN
UPSTREAM FLOW IN CFS:                  26.0
UPSTREAM AMMONIA IN mg/l:               0.0
UN-IONIZED AMMONIA STANDARD IN mg/l X 10    0.6
DISCHARGE FLOW IN MGD:                 11.6

                                                                   pH
           6.5  6.6  6.7  6.8  6.9  7.0  7.1  7.2  7.3  7.4  7.5  7.6  7.7  7.8  7.9  8.0  8.1  8.2  8.3  8.4  8.5  8.6  8.7  8.8  8.9  9.0
DEGREES
CENTIGRADE
   3.0   ************************************88.1 70.0 55.6 44.2 35.1 27.9 22.2 17.7 14.1 11.2  8.9  7.1  5.7  4.6  3.6  2.9  2.4  1.9  1.5
   4.0   ************************************81.1 64.5 51.2 40.7 32.4 25.8 20.5 16.3 13.0 10.3  8.2  6.6  5.3  4.2  3.4  2.7  2.2  1.8  1.4
   5.0   *******************************94.1 74.8 59.4 47.2 37.6 29.9 23.8 18.9 15.0 12.0  9.5  7.6  6.1  4.9  3.9  3.1  2.5  2.0  1.6  1.3
   6.0   *******************************86.8 69.0 54.8 43.6 34.6 27.6 21.9 17.4 13.9 11.1  8.8  7.0  5.6  4.5  3.6  2.9  2.3  1.9  1.5  1.2
   7.0   *******************************80.1 63.7 50.5 40.2 32.0 25.4 20.2 16.1 12.8 10.2  8.1  6.5  5.2  4.2  3.3  2.7  2.2  1.7  1.4  1.2
   8.0   **************************93.1 74.0 58.8 46.7 37.2 29.5 23.5 18.7 14.9 11.8  9.4  7.5  6.0  4.8  3.8  3.1  2.5  2.0  1.6  1.3  1.1
   9.0   **************************86.0 68.4 54.3 43.2 34.3 27.3 21.7 17.3 13.8 11.0  8.7  7.0  5.6  4.5  3.6  2.9  2.3  1.9  1.5  1.2  1.0
  10.0   **************************79.5 63.2 50.2 39.9 31.7 25.2 20.1 16.0 12.7 10.1  8.1  6.5  5.2  4.1  3.3  2.7  2.1  1.7  1.4  1.1  0.9
  11.0   *********************92.6 73.6 58.5 46.5 36.9 29.4 23.4 18.6 14.8 11.8  9.4  7.5  6.0  4.8  3.8  3.1  2.5  2.0  1.6  1.3  1.1  0.9
  12.0   *********************85.7 68.1 54.1 43.0 34.2 27.2 21.6 17.2 13.7 10.9  8.7  6.9  5.5  4.4  3.6  2.9  2.3  1.9  1.5  1.2  1.0  0.8
  13.0   ****************99.8 79.3 63.0 50.1 39.8 31.7 25.2 20.0 15.9 12.7 10.1  8.1  6.4  5.1  4.1  3.3  2.7  2.1  1.7  1.4  1.1  0.9  0.8
  14.0   ****************92.5 73.5 58.4 46.4 36.9 29.3 23.3 18.6 14.8 11.8  9.4  7.5  6.0  4.8  3.8  3.1  2.5  2.0  1.6  1.3  1.1  0.9  0.7
  15.0   ****************85.7 68.1 54.1 43.0 34.2 27.2 21.6 17.2 13.7 10.9  8.7  6.9  5.5  4.4  3.6  2.9  2.3  1.9  1.5  1.2  1.0  0.8  0.7
  16.0   ****************79.5 63.2 50.2 39.9 31.7 25.2 20.1 16.0 12.7 10.1  8.1  6.5  5.2  4.1  3.3  2.7  2.1  1.7  1.4  1.1  0.9  0.8  0.6
  17.0   ***********92.8 73.8 58.6 46.6 37.1 29.5 23.4 18.6 14.8 11.8  9.4  7.5  6.0  4.8  3.8  3.1  2.5  2.0  1.6  1.3  1.1  0.9  0.7  0.6
  18.0   ***********86.2 68.5 54.4 43.3 34.4 27.4 21.8 17.3 13.8 11.0  8.8  7.0  5.6  4.5  3.6  2.9  2.3  1.9  1.5  1.2  1.0  0.8  0.7  0.6
  19.0   ***********80.1 63.6 50.6 40.2 32.0 25.4 20.2 16.1 12.8 10.2  8.1  6.5  5.2  4.2  3.3  2.7  2.2  1.7  1.4  1.2  0.9  0.8  0.7  0.5
  20.0   ******93.6 74.4 59.1 47.0 37.4 29.7 23.6 18.8 15.0 11.9  9.5  7.6  6.0  4.8  3.9  3.1  2.5  2.0  1.6  1.3  1.1  0.9  0.7  0.6  0.5
  21.0   ******87.1 69.2 55.0 43.7 34.8 27.6 22.0 17.5 13.9 11.1  8.8  7.1  5.6  4.5  3.6  2.9  2.3  1.9  1.5  1.2  1.0  0.8  0.7  0.6  0.5
  22.0   ******81.0 64.4 51.2 40.7 32.3 25.7 20.5 16.3 13.0 10.3  8.2  6.6  5.2  4.2  3.4  2.7  2.2  1.8  1.4  1.2  1.0  0.8  0.7  0.6  0.5
  23.0    94.9 75.4 59.9 47.6 37.9 30.1 23.9 19.0 15.2 12.1  9.6  7.7  6.1  4.9  3.9  3.1  2.5  2.0  1.6  1.3  1.1  0.9  0.7  0.6  0.5  0.4
  24.0    88.3 70.2 55.8 44.3 35.3 28.0 22.3 17.7 14.1 11.2  9.0  7.2  5.7  4.6  3.7  2.9  2.4  1.9  1.5  1.3  1.0  0.8  0.7  0.6  0.5  0.4
  25.0    82.3 65.4 52.0 41.3 32.9 26.1 20.8 16.5 13.2 10.5  8.4  6.7  5.3  4.3  3.4  2.7  2.2  1.8  1.4  1.2  1.0  0.8  0.7  0.6  0.5  0.4
```

Table B3.4 Ammonia effluent limits for the City of Longmont based on a 7Q10 chronic design flow and an instream ammonia standard of 0.10 mg/l-N.

```
DISCHARGER: LONGMONT             STREAM: SAINT VRAIN
UPSTREAM FLOW IN CFS:                     12.0
UPSTREAM AMMONIA IN mg/l:                  0.0
UN-IONIZED AMMONIA STANDARD IN mg/l X 10   1.0
DISCHARGE FLOW IN MGD:                    11.6

                                                                  pH
            6.5  6.6  6.7  6.8  6.9  7.0  7.1  7.2  7.3  7.4  7.5  7.6  7.7  7.8  7.9  8.0  8.1  8.2  8.3  8.4  8.5  8.6  8.7  8.8  8.9  9.0
DEGREES
CENTIGRADE
  3.0     ************************************99.9 79.4 63.1 50.2 39.9 31.7 25.2 20.1 16.0 12.7 10.1  8.1  6.5  5.2  4.1  3.3  2.7  2.2  1.7
  4.0     ************************************92.1 73.2 58.1 46.2 36.8 29.2 23.3 18.5 14.7 11.7  9.4  7.5  6.0  4.8  3.8  3.1  2.5  2.0  1.6
  5.0     ************************************84.9 67.4 53.6 42.6 33.9 27.0 21.4 17.1 13.6 10.8  8.6  6.9  5.5  4.4  3.5  2.8  2.3  1.9  1.5
  6.0     *******************************98.5 78.3 62.2 49.5 39.3 31.3 24.9 19.8 15.8 12.5 10.0  8.0  6.4  5.1  4.1  3.3  2.6  2.1  1.7  1.4
  7.0     *******************************90.9 72.2 57.4 45.6 36.3 28.9 23.0 18.3 14.5 11.6  9.2  7.4  5.9  4.7  3.8  3.0  2.4  2.0  1.6  1.3
  8.0     *******************************83.9 66.7 53.0 42.2 33.5 26.7 21.2 16.9 13.4 10.7  8.5  6.8  5.5  4.4  3.5  2.8  2.3  1.8  1.5  1.2
  9.0     **************************97.6 77.6 61.6 49.0 39.0 31.0 24.6 19.6 15.6 12.4  9.9  7.9  6.3  5.1  4.0  3.2  2.6  2.1  1.7  1.4  1.1
 10.0     **************************90.2 71.7 57.0 45.3 36.0 28.6 22.8 18.1 14.4 11.5  9.2  7.3  5.9  4.7  3.8  3.0  2.4  2.0  1.6  1.3  1.1
 11.0     **************************83.5 66.3 52.7 41.9 33.3 26.5 21.1 16.8 13.4 10.7  8.5  6.8  5.4  4.3  3.5  2.8  2.3  1.8  1.5  1.2  1.0
 12.0     *********************97.2 77.2 61.4 48.8 38.8 30.9 24.5 19.5 15.5 12.4  9.9  7.9  6.3  5.0  4.0  3.2  2.6  2.1  1.7  1.4  1.1  0.9
 13.0     *********************90.0 71.5 56.9 45.2 35.9 28.6 22.7 18.1 14.4 11.5  9.2  7.3  5.8  4.7  3.7  3.0  2.4  2.0  1.6  1.3  1.1  0.9
 14.0     *********************83.4 66.3 52.7 41.9 33.3 26.5 21.1 16.8 13.4 10.6  8.5  6.8  5.4  4.3  3.5  2.8  2.3  1.8  1.5  1.2  1.0  0.8
 15.0     ****************97.3 77.3 61.4 48.8 38.8 30.9 24.6 19.5 15.6 12.4  9.9  7.9  6.3  5.0  4.0  3.2  2.6  2.1  1.7  1.4  1.1  0.9  0.8
 16.0     ****************90.2 71.7 57.0 45.3 36.0 28.6 22.8 18.1 14.4 11.5  9.2  7.3  5.8  4.7  3.8  3.0  2.4  2.0  1.6  1.3  1.1  0.9  0.7
 17.0     ****************83.7 66.5 52.9 42.0 33.4 26.6 21.2 16.8 13.4 10.7  8.5  6.8  5.4  4.4  3.5  2.8  2.3  1.8  1.5  1.2  1.0  0.8  0.7
 18.0     ***********97.8 77.7 61.8 49.1 39.0 31.0 24.7 19.7 15.6 12.5  9.9  7.9  6.3  5.1  4.1  3.3  2.6  2.1  1.7  1.4  1.1  0.9  0.8  0.7
 19.0     ***********90.9 72.2 57.4 45.6 36.3 28.8 22.9 18.3 14.5 11.6  9.2  7.4  5.9  4.7  3.8  3.0  2.4  2.0  1.6  1.3  1.1  0.9  0.7  0.6
 20.0     ***********84.4 67.1 53.3 42.4 33.7 26.8 21.3 17.0 13.5 10.8  8.6  6.9  5.5  4.4  3.5  2.8  2.3  1.8  1.5  1.2  1.0  0.8  0.7  0.6
 21.0     ******98.8 78.5 62.4 49.6 39.4 31.4 24.9 19.8 15.8 12.6 10.0  8.0  6.4  5.1  4.1  3.3  2.6  2.1  1.7  1.4  1.2  1.0  0.8  0.7  0.6
 22.0     ******91.9 73.0 58.1 46.1 36.7 29.2 23.2 18.5 14.7 11.7  9.3  7.5  6.0  4.8  3.8  3.1  2.5  2.0  1.6  1.3  1.1  0.9  0.7  0.6  0.5
 23.0     ******85.5 68.0 54.0 43.0 34.2 27.2 21.6 17.2 13.7 10.9  8.7  6.9  5.6  4.4  3.6  2.9  2.3  1.9  1.5  1.2  1.0  0.8  0.7  0.6  0.5
 24.0     ******79.7 63.3 50.3 40.0 31.8 25.3 20.1 16.0 12.8 10.2  8.1  6.5  5.2  4.2  3.3  2.7  2.2  1.8  1.4  1.2  1.0  0.8  0.7  0.6  0.5
 25.0      93.4 74.2 59.0 45.9 37.3 29.6 23.6 18.8 14.9 11.9  9.5  7.6  6.0  4.8  3.9  3.1  2.5  2.0  1.6  1.3  1.1  0.9  0.8  0.6  0.5  0.5
```

Table B3.5 Ammonia effluent limits for the City of Longmont based on a 30Q10 chronic design flow and an instream ammonia standard of 0.10 mg/l-N.

```
DISCHARGER: LONGMONT            STREAM: SAINT VRAIN
UPSTREAM FLOW IN CFS:                       18.0
UPSTREAM AMMONIA IN mg/l:                    0.0
UN-IONIZED AMMONIA STANDARD IN mg/l X 10     1.0
DISCHARGE FLOW IN MGD:                      11.6

                                                                     pH
           6.5  6.6  6.7  6.8  6.9  7.0  7.1  7.2  7.3  7.4  7.5  7.6  7.7  7.8  7.9  8.0  8.1  8.2  8.3  8.4  8.5  8.6  8.7  8.8  8.9  9.0
DEGREES
CENTIGRADE
  3.0    *****************************************95.4 75.8 60.2 47.9 38.1 30.3 24.1 19.2 15.3 12.2  9.7  7.8  6.2  5.0  4.0  3.2  2.6  2.1
  4.0    *****************************************87.9 69.8 55.5 44.1 35.1 27.9 22.2 17.7 14.1 11.2  9.0  7.2  5.7  4.6  3.7  3.0  2.4  1.9
  5.0    *****************************************81.0 64.4 51.2 40.7 32.4 25.8 20.5 16.3 13.0 10.4  8.3  6.6  5.3  4.3  3.4  2.8  2.2  1.8
  6.0    ************************************94.0 74.7 59.4 47.2 37.5 29.9 23.8 18.9 15.1 12.0  9.6  7.7  6.1  4.9  3.9  3.2  2.6  2.1  1.7
  7.0    ************************************86.8 69.0 54.8 43.6 34.7 27.6 21.9 17.5 13.9 11.1  8.9  7.1  5.7  4.5  3.6  2.9  2.4  1.9  1.6
  8.0    ************************************80.1 63.7 50.6 40.3 32.0 25.5 20.3 16.1 12.9 10.3  8.2  6.5  5.2  4.2  3.4  2.7  2.2  1.8  1.5
  9.0    *******************************93.1 74.0 58.8 46.8 37.2 29.6 23.5 18.7 14.9 11.9  9.5  7.6  6.1  4.9  3.9  3.1  2.5  2.1  1.7  1.4
 10.0    *******************************86.1 68.4 54.4 43.3 34.4 27.4 21.8 17.3 13.8 11.0  8.8  7.0  5.6  4.5  3.6  2.9  2.4  1.9  1.6  1.3
 11.0    *******************************79.7 63.3 50.3 40.0 31.8 25.3 20.2 16.1 12.8 10.2  8.1  6.5  5.2  4.2  3.4  2.7  2.2  1.8  1.5  1.2
 12.0    **************************92.8 73.7 58.6 46.6 37.1 29.5 23.5 18.7 14.9 11.9  9.5  7.6  6.0  4.8  3.9  3.1  2.5  2.0  1.7  1.4  1.1
 13.0    **************************85.9 68.3 54.3 43.2 34.3 27.3 21.7 17.3 13.8 11.0  8.8  7.0  5.6  4.5  3.6  2.9  2.4  1.9  1.6  1.3  1.1
 14.0    **************************79.6 63.3 50.3 40.0 31.8 25.3 20.1 16.0 12.8 10.2  8.1  6.5  5.2  4.2  3.4  2.7  2.2  1.8  1.5  1.2  1.0
 15.0    *********************92.8 73.8 58.6 46.6 37.1 29.5 23.5 18.7 14.9 11.9  9.5  7.6  6.0  4.8  3.9  3.1  2.5  2.0  1.7  1.4  1.1  0.9
 16.0    *********************86.1 68.4 54.4 43.3 34.4 27.4 21.8 17.3 13.8 11.0  8.8  7.0  5.6  4.5  3.6  2.9  2.4  1.9  1.6  1.3  1.1  0.9
 17.0    *********************79.9 63.5 50.5 40.1 31.9 25.4 20.2 16.1 12.8 10.2  8.2  6.5  5.2  4.2  3.4  2.7  2.2  1.8  1.5  1.2  1.0  0.8
 18.0    ****************93.3 74.2 59.0 46.9 37.3 29.7 23.6 18.8 15.0 11.9  9.5  7.6  6.1  4.9  3.9  3.1  2.5  2.1  1.7  1.4  1.1  0.9  0.8
 19.0    ****************86.7 68.9 54.8 43.6 34.6 27.6 21.9 17.5 13.9 11.1  8.9  7.1  5.7  4.5  3.6  2.9  2.4  1.9  1.6  1.3  1.1  0.9  0.7
 20.0    ****************80.6 64.1 50.9 40.5 32.2 25.6 20.4 16.2 12.9 10.3  8.2  6.6  5.3  4.2  3.4  2.7  2.2  1.8  1.5  1.2  1.0  0.8  0.7
 21.0    ***********94.3 74.9 59.6 47.4 37.7 30.0 23.8 19.0 15.1 12.0  9.6  7.7  6.1  4.9  3.9  3.2  2.6  2.1  1.7  1.4  1.1  0.9  0.8  0.7
 22.0    ***********87.7 69.7 55.4 44.1 35.0 27.8 22.2 17.7 14.1 11.2  9.0  7.2  5.7  4.6  3.7  3.0  2.4  1.9  1.6  1.3  1.1  0.9  0.8  0.6
 23.0    ***********81.6 64.9 51.6 41.0 32.6 26.0 20.7 16.5 13.1 10.5  8.3  6.7  5.3  4.3  3.4  2.8  2.2  1.8  1.5  1.2  1.0  0.8  0.7  0.6
 24.0    ******95.7 76.0 60.4 48.0 38.2 30.4 24.2 19.2 15.3 12.2  9.7  7.8  6.2  5.0  4.0  3.2  2.6  2.1  1.7  1.4  1.2  1.0  0.8  0.7  0.6
 25.0    ******89.1 70.6 56.3 44.8 35.6 28.3 22.5 17.9 14.3 11.4  9.1  7.3  5.8  4.7  3.7  3.0  2.4  2.0  1.6  1.3  1.1  0.9  0.8  0.6  0.6
```

Table B3.6 Ammonia effluent limits for the City of Longmont based on a 30Q3 chronic design flow and an instream ammonia standard of 0.10 mg/l-N.

```
DISCHARGER: LONGMONT            STREAM: SAINT VRAIN
UPSTREAM FLOW IN CFS:                   26.0
UPSTREAM AMMONIA IN mg/l:                0.0
UN-IONIZED AMMONIA STANDARD IN mg/l X 10 1.0
DISCHARGE FLOW IN MGD:                  11.6

                                                 pH
           6.5  6.6  6.7  6.8  6.9  7.0  7.1  7.2  7.3  7.4  7.5  7.6  7.7  7.8  7.9  8.0  8.1  8.2  8.3  8.4  8.5  8.6  8.7  8.8  8.9  9.0
DEGREES
CENTIGRADE
   3.0    **********************************************92.7 73.7 58.6 46.6 37.1 29.5 23.5 18.7 14.9 11.9  9.5  7.6  6.1  4.9  3.9  3.2  2.6
   4.0    **********************************************85.4 67.9 54.0 42.9 34.1 27.2 21.6 17.2 13.7 11.0  8.8  7.0  5.6  4.5  3.6  2.9  2.4
   5.0    *****************************************99.1 78.7 62.6 49.8 39.6 31.5 25.1 20.0 15.9 12.7 10.1  8.1  6.5  5.2  4.2  3.4  2.7  2.2
   6.0    *****************************************91.4 72.6 57.7 45.9 36.5 29.1 23.1 18.4 14.7 11.7  9.4  7.5  6.0  4.8  3.9  3.1  2.5  2.1
   7.0    *****************************************84.3 67.0 53.3 42.4 33.7 26.8 21.4 17.0 13.6 10.8  8.7  6.9  5.6  4.5  3.6  2.9  2.4  1.9
   8.0    ************************************98.0 77.9 61.9 49.2 39.2 31.2 24.8 19.7 15.7 12.6 10.0  8.0  6.4  5.1  4.1  3.3  2.7  2.2  1.8
   9.0    ************************************90.5 72.0 57.2 45.5 36.2 28.8 22.9 18.3 14.6 11.6  9.3  7.4  5.9  4.8  3.8  3.1  2.5  2.0  1.7
  10.0    ************************************83.7 66.5 52.9 42.1 33.5 26.6 21.2 16.9 13.5 10.8  8.6  6.9  5.5  4.4  3.6  2.9  2.3  1.9  1.6
  11.0    *******************************97.4 77.4 61.6 49.0 38.9 31.0 24.7 19.6 15.6 12.5 10.0  8.0  6.4  5.1  4.1  3.3  2.7  2.2  1.8  1.5
  12.0    *******************************90.2 71.7 57.0 45.3 36.0 28.7 22.8 18.2 14.5 11.6  9.2  7.4  5.9  4.8  3.8  3.1  2.5  2.0  1.7  1.4
  13.0    *******************************83.5 66.4 52.8 42.0 33.4 26.6 21.2 16.9 13.4 10.7  8.6  6.9  5.5  4.4  3.6  2.9  2.3  1.9  1.6  1.3
  14.0    **************************97.3 77.4 61.5 48.9 38.9 31.0 24.6 19.6 15.6 12.5 10.0  8.0  6.4  5.1  4.1  3.3  2.7  2.2  1.8  1.5  1.2
  15.0    **************************90.2 71.7 57.0 45.3 36.1 28.7 22.9 18.2 14.5 11.6  9.2  7.4  5.9  4.8  3.8  3.1  2.5  2.0  1.7  1.4  1.1
  16.0    **************************83.7 66.5 52.9 42.1 33.5 26.6 21.2 16.9 13.5 10.8  8.6  6.9  5.5  4.4  3.6  2.9  2.3  1.9  1.6  1.3  1.1
  17.0    *********************97.7 77.7 61.8 49.1 39.1 31.1 24.7 19.7 15.7 12.5 10.0  8.0  6.4  5.1  4.1  3.3  2.7  2.2  1.8  1.5  1.2  1.0
  18.0    *********************90.7 72.1 57.3 45.6 36.3 28.9 23.0 18.3 14.6 11.6  9.3  7.4  6.0  4.8  3.8  3.1  2.5  2.1  1.7  1.4  1.2  1.0
  19.0    *********************84.3 67.0 53.3 42.4 33.7 26.8 21.4 17.0 13.6 10.8  8.6  6.9  5.5  4.5  3.6  2.9  2.4  1.9  1.6  1.3  1.1  0.9
  20.0    ****************98.6 78.3 62.3 49.5 39.4 31.3 24.9 19.9 15.8 12.6 10.1  8.1  6.4  5.2  4.2  3.4  2.7  2.2  1.8  1.5  1.2  1.0  0.9
  21.0    ****************91.7 72.9 57.9 46.1 36.6 29.2 23.2 18.5 14.7 11.8  9.4  7.5  6.0  4.8  3.9  3.1  2.5  2.1  1.7  1.4  1.2  1.0  0.8
  22.0    ****************85.3 67.8 53.9 42.9 34.1 27.1 21.6 17.2 13.7 10.9  8.7  7.0  5.6  4.5  3.6  2.9  2.4  1.9  1.6  1.3  1.1  0.9  0.8
  23.0    ***********99.9 79.4 63.1 50.2 39.9 31.7 25.3 20.1 16.0 12.8 10.2  8.2  6.5  5.2  4.2  3.4  2.7  2.2  1.8  1.5  1.2  1.0  0.9  0.7
  24.0    ***********93.0 73.9 58.8 46.7 37.2 29.6 23.5 18.7 14.9 11.9  9.5  7.6  6.1  4.9  3.9  3.2  2.6  2.1  1.7  1.4  1.2  1.0  0.8  0.7
  25.0    ***********86.6 68.9 54.8 43.5 34.6 27.6 21.9 17.5 13.9 11.1  8.9  7.1  5.7  4.6  3.7  3.0  2.4  2.0  1.6  1.3  1.1  0.9  0.8  0.7
```

Table B3.7 Ammonia effluent limits for the City of Longmont based on actual effluent flows on a 7Q10 chronic design flow and an instream ammonia standard of 0.06 mg/l-N.

```
DISCHARGER: LONGMONT              STREAM: SAINT VRAIN
UPSTREAM FLOW IN CFS:                       12.0
UPSTREAM AMMONIA IN mg/l:                    0.0
UN-IONIZED AMMONIA STANDARD IN mg/l X 10     1.0
DISCHARGE FLOW IN MGD:                       8.5

                                                           pH
          6.5  6.6  6.7  6.8  6.9  7.0  7.1  7.2  7.3  7.4  7.5  7.6  7.7  7.8  7.9  8.0  8.1  8.2  8.3  8.4  8.5  8.6  8.7  8.8  8.9  9.0
DEGREES
CENTIGRADE
  3.0    ****************************************90.9 72.2 57.4 45.6 36.3 28.9 23.0 18.3 14.6 11.6  9.3  7.4  5.9  4.7  3.8  3.1  2.5  2.0
  4.0    ****************************************83.7 66.5 52.9 42.0 33.4 26.6 21.2 16.9 13.4 10.7  8.5  6.8  5.5  4.4  3.5  2.8  2.3  1.9
  5.0    ***********************************97.1 77.2 61.3 48.8 38.8 30.8 24.5 19.5 15.6 12.4  9.9  7.9  6.3  5.0  4.0  3.3  2.6  2.1  1.7
  6.0    ***********************************89.6 71.2 56.6 45.0 35.6 28.5 22.6 18.0 14.4 11.4  9.1  7.3  5.8  4.7  3.7  3.0  2.4  2.0  1.6
  7.0    ***********************************82.7 65.7 52.2 41.5 33.0 26.3 20.9 16.6 13.3 10.6  8.4  6.7  5.4  4.3  3.5  2.8  2.3  1.8  1.5
  8.0    ******************************96.1 76.3 60.7 48.2 38.4 30.5 24.3 19.3 15.4 12.3  9.8  7.8  6.2  5.0  4.0  3.2  2.6  2.1  1.7  1.4
  9.0    ******************************88.7 70.5 56.1 44.6 35.4 28.2 22.4 17.9 14.2 11.3  9.0  7.2  5.8  4.6  3.7  3.0  2.4  2.0  1.6  1.3
 10.0    ******************************82.0 65.2 51.8 41.2 32.8 26.1 20.8 16.5 13.2 10.5  8.4  6.7  5.4  4.3  3.5  2.8  2.2  1.8  1.5  1.2
 11.0    *************************95.5 75.9 60.3 48.0 38.1 30.3 24.1 19.2 15.3 12.2  9.7  7.8  6.2  5.0  4.0  3.2  2.6  2.1  1.7  1.4  1.1
 12.0    *************************88.4 70.2 55.8 44.4 35.3 28.1 22.3 17.8 14.2 11.3  9.0  7.2  5.8  4.6  3.7  3.0  2.4  2.0  1.6  1.3  1.1
 13.0    *************************81.8 65.1 51.7 41.1 32.7 26.0 20.7 16.5 13.1 10.5  6.4  6.7  5.3  4.3  3.4  2.8  2.2  1.8  1.5  1.2  1.0
 14.0    ********************95.4 75.8 60.3 47.9 38.1 30.3 24.1 19.2 15.3 12.2  9.7  7.8  6.2  5.0  4.0  3.2  2.6  2.1  1.7  1.4  1.1  0.9
 15.0    ********************88.5 70.3 55.9 44.4 35.3 28.1 22.4 17.8 14.2 11.3  9.0  7.2  5.8  4.6  3.7  3.0  2.4  2.0  1.6  1.3  1.1  0.9
 16.0    ********************82.0 65.2 51.8 41.2 32.8 26.1 20.8 16.5 13.2 10.5  8.4  6.7  5.4  4.3  3.4  2.8  2.2  1.8  1.5  1.2  1.0  0.8
 17.0    ***************95.8 76.1 60.5 48.1 38.3 30.4 24.2 19.3 15.3 12.2  9.8  7.8  6.2  5.0  4.0  3.2  2.6  2.1  1.7  1.4  1.1  1.0  0.8
 18.0    ***************88.9 70.7 56.2 44.7 35.5 28.3 22.5 17.9 14.3 11.4  9.1  7.2  5.8  4.6  3.7  3.0  2.4  2.0  1.6  1.3  1.1  0.9  0.8
 19.0    ***************82.6 65.7 52.2 41.5 33.0 26.3 20.9 16.6 13.3 10.6  8.4  6.7  5.4  4.3  3.5  2.8  2.3  1.8  1.5  1.2  1.0  0.8  0.7
 20.0    **********96.6 76.9 61.0 48.5 38.6 30.7 24.4 19.4 15.5 12.3  9.8  7.9  6.3  5.0  4.0  3.2  2.6  2.1  1.7  1.4  1.2  1.0  0.8  0.7
 21.0    **********89.8 71.4 56.8 45.1 35.9 28.5 22.7 18.1 14.4 11.5  9.2  7.3  5.8  4.7  3.8  3.0  2.4  2.0  1.6  1.3  1.1  0.9  0.8  0.6
 22.0    **********83.6 66.4 52.8 42.0 33.4 26.6 21.1 16.8 13.4 10.7  8.5  6.8  5.5  4.4  3.5  2.8  2.3  1.9  1.5  1.2  1.0  0.9  0.7  0.6
 23.0    *****97.9 77.8 61.8 49.2 39.1 31.1 24.7 19.7 15.7 12.5 10.0  8.0  6.4  5.1  4.1  3.3  2.6  2.1  1.7  1.4  1.2  1.0  0.8  0.7  0.6
 24.0    *****91.1 72.4 57.6 45.8 36.4 29.0 23.0 18.3 14.6 11.6  9.3  7.4  5.9  4.7  3.8  3.1  2.5  2.0  1.6  1.3  1.1  0.9  0.8  0.6  0.6
 25.0    *****84.9 67.5 53.6 42.7 33.9 27.0 21.5 17.1 13.6 10.9  8.7  6.9  5.5  4.4  3.6  2.9  2.3  1.9  1.5  1.3  1.0  0.9  0.7  0.6  0.5
```

Table B3.8 Ammonia effluent limits for the City of Longmont based on a 1Q10 acute design flow and an instream ammonia standard of 0.20 mg/l-N.

```
DISCHARGER: LONGMONT              STREAM: SAINT VRAIN
UPSTREAM FLOW IN CFS:                        10.0
UPSTREAM AMMONIA IN mg/l:                     0.0
UN-IONIZED AMMONIA STANDARD IN mg/l X 10      2.0
DISCHARGE FLOW IN MGD:                       11.6
```

DEGREES CENTIGRADE	pH 6.5	6.6	6.7	6.8	6.9	7.0	7.1	7.2	7.3	7.4	7.5	7.6	7.7	7.8	7.9	8.0	8.1	8.2	8.3	8.4	8.5	8.6	8.7	8.8	8.9	9.0
3.0	*****	*****	*****	*****	*****	*****	*****	93.2	74.1	58.9	46.8	37.2	29.6	23.5	18.7	14.9	11.9	9.5	7.5	6.0	4.8	3.9	3.1	2.5	2.0	1.6
4.0	*****	*****	*****	*****	*****	*****	*****	85.9	68.3	54.3	43.1	34.3	27.3	21.7	17.3	13.7	11.0	8.7	7.0	5.6	4.5	3.6	2.9	2.3	1.9	1.5
5.0	*****	*****	*****	*****	*****	*****	99.6	79.2	62.9	50.0	39.8	31.6	25.1	20.0	15.9	12.7	10.1	8.1	6.4	5.1	4.1	3.3	2.7	2.1	1.7	1.4
6.0	*****	*****	*****	*****	*****	*****	91.9	73.0	58.0	46.1	36.7	29.2	23.2	18.5	14.7	11.7	9.3	7.4	5.9	4.8	3.8	3.1	2.5	2.0	1.6	1.3
7.0	*****	*****	*****	*****	*****	*****	84.8	67.4	53.6	42.6	33.9	26.9	21.4	17.0	13.6	10.8	8.6	6.9	5.5	4.4	3.5	2.8	2.3	1.8	1.5	1.2
8.0	*****	*****	*****	*****	*****	98.6	78.3	62.3	49.5	39.3	31.3	24.9	19.8	15.8	12.5	10.0	8.0	6.4	5.1	4.1	3.3	2.6	2.1	1.7	1.4	1.1
9.0	*****	*****	*****	*****	*****	91.1	72.4	57.5	45.7	36.4	28.9	23.0	18.3	14.6	11.6	9.2	7.4	5.9	4.7	3.8	3.0	2.4	2.0	1.6	1.3	1.1
10.0	*****	*****	*****	*****	*****	84.2	66.9	53.2	42.3	33.6	26.7	21.3	16.9	13.5	10.7	8.6	6.8	5.5	4.4	3.5	2.8	2.3	1.8	1.5	1.2	1.0
11.0	*****	*****	*****	*****	98.0	77.9	61.9	49.2	39.1	31.1	24.7	19.7	15.7	12.5	9.9	7.9	6.3	5.1	4.1	3.3	2.6	2.1	1.7	1.4	1.1	0.9
12.0	*****	*****	*****	*****	90.7	72.1	57.3	45.5	36.2	28.8	22.9	18.2	14.5	11.6	9.2	7.3	5.9	4.7	3.8	3.0	2.4	2.0	1.6	1.3	1.1	0.9
13.0	*****	*****	*****	*****	84.0	66.7	53.0	42.2	33.5	26.7	21.2	16.9	13.4	10.7	8.5	6.8	5.4	4.4	3.5	2.8	2.3	1.8	1.5	1.2	1.0	0.8
14.0	*****	*****	*****	97.9	77.8	61.8	49.2	39.1	31.1	24.7	19.7	15.7	12.5	9.9	7.9	6.3	5.1	4.0	3.2	2.6	2.1	1.7	1.4	1.1	0.9	0.8
15.0	*****	*****	*****	90.8	72.1	57.3	45.6	36.2	28.8	22.9	18.2	14.5	11.6	9.2	7.4	5.9	4.7	3.8	3.0	2.4	2.0	1.6	1.3	1.1	0.9	0.7
16.0	*****	*****	*****	84.2	66.9	53.2	42.3	33.6	26.7	21.3	16.9	13.5	10.7	8.6	6.8	5.5	4.4	3.5	2.8	2.3	1.8	1.5	1.2	1.0	0.8	0.7
17.0	*****	*****	98.3	78.1	62.1	49.3	39.2	31.2	24.8	19.7	15.7	12.5	10.0	8.0	6.3	5.1	4.1	3.3	2.6	2.1	1.7	1.4	1.1	0.9	0.8	0.6
18.0	*****	*****	91.3	72.5	57.6	45.8	36.4	29.0	23.0	18.3	14.6	11.6	9.3	7.4	5.9	4.7	3.8	3.0	2.4	2.0	1.6	1.3	1.1	0.9	0.7	0.6
19.0	*****	*****	84.8	67.4	53.5	42.6	33.8	26.9	21.4	17.0	13.6	10.8	6.6	6.9	5.5	4.4	3.5	2.8	2.3	1.8	1.5	1.2	1.0	0.8	0.7	0.6
20.0	*****	99.1	78.8	62.6	49.8	39.6	31.5	25.0	19.9	15.8	12.6	10.1	8.0	6.4	5.1	4.1	3.3	2.6	2.1	1.7	1.4	1.1	0.9	0.8	0.7	0.6
21.0	*****	92.2	73.3	58.2	46.3	36.8	29.3	23.3	18.5	14.7	11.7	9.4	7.5	6.0	4.8	3.8	3.1	2.5	2.0	1.6	1.3	1.1	0.9	0.7	0.6	0.5
22.0	*****	85.8	68.2	54.2	43.1	34.2	27.2	21.7	17.2	13.7	10.9	8.7	7.0	5.6	4.4	3.6	2.9	2.3	1.9	1.5	1.2	1.0	0.8	0.7	0.6	0.5
23.0	*****	79.8	63.4	50.4	40.1	31.9	25.3	20.2	16.1	12.8	10.2	8.1	6.5	5.2	4.1	3.3	2.7	2.2	1.7	1.4	1.2	1.0	0.8	0.7	0.6	0.5
24.0	93.5	74.3	59.1	47.0	37.3	29.7	23.6	18.8	15.0	11.9	9.5	7.6	6.0	4.8	3.9	3.1	2.5	2.0	1.6	1.3	1.1	0.9	0.7	0.6	0.5	0.5
25.0	87.1	69.2	55.0	43.7	34.8	27.7	22.0	17.5	13.9	11.1	8.9	7.1	5.6	4.5	3.6	2.9	2.3	1.9	1.5	1.3	1.0	0.8	0.7	0.6	0.5	0.4

Table B3.9 Ammonia effluent limits for the City of Longmont based on a 1Q3 acute design flow and an instream ammonia standard of 0.20 mg/l-N.

DISCHARGER: LONGMONT, COLORADO STREAM: ST. VRAIN
UPSTREAM FLOW IN CFS: 15.0
UPSTREAM AMMONIA IN mg/l: 0.0
UN-IONIZED AMMONIA STANDARD IN mg/l X 10 2.0
DISCHARGE FLOW IN MGD: 11.6

	pH																									
DEGREES CENTIGRADE	6.5	6.6	6.7	6.8	6.9	7.0	7.1	7.2	7.3	7.4	7.5	7.6	7.7	7.8	7.9	8.0	8.1	8.2	8.3	8.4	8.5	8.6	8.7	8.8	8.9	9.0
3.0	****	****	****	****	****	****	****	****	****	****	****	87.6	69.7	55.4	44.1	35.1	28.0	22.3	17.8	14.2	11.3	9.1	7.3	5.9	4.7	3.8
4.0	****	****	****	****	****	****	****	****	****	****	****	80.7	64.2	51.1	40.6	32.4	25.8	20.5	16.4	13.1	10.5	8.4	6.8	5.4	4.4	3.6
5.0	****	****	****	****	****	****	****	****	****	****	93.6	74.4	59.2	47.1	37.5	29.9	23.8	19.0	15.1	12.1	9.7	7.8	6.3	5.0	4.1	3.3
6.0	****	****	****	****	****	****	****	****	****	****	86.4	68.7	54.6	43.5	34.6	27.6	22.0	17.5	14.0	11.2	9.0	7.2	5.8	4.7	3.8	3.1
7.0	****	****	****	****	****	****	****	****	****	****	79.7	63.4	50.4	40.1	32.0	25.5	20.3	16.2	12.9	10.4	8.3	6.7	5.4	4.3	3.5	2.9
8.0	****	****	****	****	****	****	****	****	****	92.6	73.6	58.6	46.6	37.1	29.5	23.5	18.8	15.0	12.0	9.6	7.7	6.2	5.0	4.0	3.3	2.7
9.0	****	****	****	****	****	****	****	****	****	85.6	68.1	54.1	43.1	34.3	27.3	21.8	17.4	13.9	11.1	8.9	7.1	5.7	4.6	3.8	3.1	2.5
10.0	****	****	****	****	****	****	****	****	99.5	79.1	62.9	50.1	39.8	31.7	25.3	20.2	16.1	12.8	10.3	8.2	6.6	5.3	4.3	3.5	2.9	2.3
11.0	****	****	****	****	****	****	****	****	92.1	73.2	58.2	46.3	36.9	29.4	23.4	18.7	14.9	11.9	9.5	7.7	6.2	5.0	4.0	3.3	2.7	2.2
12.0	****	****	****	****	****	****	****	****	85.2	67.8	53.9	42.9	34.1	27.2	21.7	17.3	13.8	11.1	8.9	7.1	5.7	4.6	3.7	3.1	2.5	2.1
13.0	****	****	****	****	****	****	****	97.3	78.9	62.8	49.9	39.7	31.6	25.2	20.1	16.0	12.8	10.3	8.2	6.6	5.3	4.3	3.5	2.9	2.3	1.9
14.0	****	****	****	****	****	****	****	92.0	73.1	58.2	46.3	36.8	29.3	23.4	18.6	14.9	11.9	9.5	7.6	6.1	5.0	4.0	3.3	2.7	2.2	1.8
15.0	****	****	****	****	****	****	****	85.3	67.8	53.9	42.9	34.2	27.2	21.7	17.3	13.8	11.1	8.9	7.1	5.7	4.6	3.7	3.1	2.5	2.1	1.7
16.0	****	****	****	****	****	****	99.5	79.1	62.9	50.1	39.8	31.7	25.3	20.1	16.1	12.8	10.3	8.2	6.6	5.3	4.3	3.5	2.9	2.3	1.9	1.6
17.0	****	****	****	****	****	****	92.4	73.4	58.4	46.5	37.0	29.5	23.5	18.7	14.9	11.9	9.6	7.7	6.2	5.0	4.0	3.3	2.7	2.2	1.8	1.5
18.0	****	****	****	****	****	****	85.8	68.2	54.2	43.2	34.4	27.4	21.8	17.4	13.9	11.1	8.9	7.1	5.8	4.6	3.8	3.1	2.5	2.1	1.7	1.4
19.0	****	****	****	****	****	****	79.7	63.4	50.4	40.1	31.9	25.4	20.3	16.2	12.9	10.4	8.3	6.7	5.4	4.3	3.5	2.9	2.4	1.9	1.6	1.4
20.0	****	****	****	****	****	93.1	74.1	58.9	46.9	37.3	29.7	23.7	18.9	15.1	12.0	9.6	7.7	6.2	5.0	4.1	3.3	2.7	2.2	1.8	1.5	1.3
21.0	****	****	****	****	****	86.6	68.9	54.8	43.6	34.7	27.6	22.0	17.6	14.0	11.2	9.0	7.2	5.8	4.7	3.8	3.1	2.5	2.1	1.7	1.5	1.2
22.0	****	****	****	****	****	80.6	64.1	51.0	40.6	32.3	25.7	20.5	16.4	13.1	10.5	8.4	6.7	5.4	4.4	3.6	2.9	2.4	2.0	1.6	1.4	1.2
23.0	****	****	****	****	94.4	75.0	59.7	47.5	37.8	30.1	24.0	19.1	15.3	12.2	9.8	7.8	6.3	5.1	4.1	3.3	2.7	2.2	1.9	1.6	1.3	1.1
24.0	****	****	****	****	87.9	69.9	55.6	44.2	35.2	28.0	22.3	17.8	14.2	11.4	9.1	7.3	5.9	4.8	3.9	3.1	2.6	2.1	1.8	1.5	1.2	1.1
25.0	****	****	****	****	81.9	65.1	51.8	41.2	32.8	26.1	20.8	16.6	13.3	10.6	8.5	6.8	5.5	4.5	3.6	2.9	2.4	2.0	1.7	1.4	1.2	1.0

Table B4.1. Ammonia effluent limits for the City of Fort Collins based on 7Q10 and 30Q10 chronic design flows and an instream ammonia standard of 0.06 mg/l-N.

DISCHARGER: FORT COLLINS STREAM: CACHE LA POUDRE
UPSTREAM FLOW IN CFS: 1.4
UPSTREAM AMMONIA IN mg/l: 0.0
UN-IONIZED AMMONIA STANDARD IN mg/l X 10 0.6
DISCHARGE FLOW IN MGD: 7.0

DEGREES CENTIGRADE	pH 6.5	6.6	6.7	6.8	6.9	7.0	7.1	7.2	7.3	7.4	7.5	7.6	7.7	7.8	7.9	8.0	8.1	8.2	8.3	8.4	8.5	8.6	8.7	8.8	8.9	9.0
3.0	*****	*****	*****	*****	80.7	64.2	51.0	40.5	32.2	25.6	20.3	16.2	12.9	10.2	8.1	6.5	5.2	4.1	3.3	2.6	2.1	1.7	1.3	1.1	0.9	0.7
4.0	*****	*****	*****	93.6	74.4	59.1	47.0	37.3	29.7	23.6	18.7	14.9	11.8	9.4	7.5	6.0	4.8	3.8	3.0	2.4	1.9	1.6	1.2	1.0	0.8	0.7
5.0	*****	*****	*****	86.3	68.6	54.5	43.3	34.4	27.3	21.7	17.3	13.7	10.9	8.7	6.9	5.5	4.4	3.5	2.8	2.2	1.8	1.4	1.2	0.9	0.8	0.6
6.0	*****	*****	*****	79.6	63.2	50.2	39.9	31.7	25.2	20.0	15.9	12.7	10.1	8.0	6.4	5.1	4.1	3.2	2.6	2.1	1.7	1.3	1.1	0.9	0.7	0.6
7.0	*****	*****	92.5	73.5	58.4	46.4	36.8	29.3	23.3	18.5	14.7	11.7	9.3	7.4	5.9	4.7	3.7	3.0	2.4	1.9	1.5	1.2	1.0	0.8	0.7	0.5
8.0	*****	*****	85.4	67.8	53.9	42.8	34.0	27.0	21.5	17.1	13.6	10.8	8.6	6.8	5.5	4.3	3.5	2.8	2.2	1.8	1.4	1.1	0.9	0.7	0.6	0.5
9.0	*****	99.3	78.9	62.7	49.8	39.6	31.4	25.0	19.9	15.8	12.6	10.0	7.9	6.3	5.0	4.0	3.2	2.6	2.0	1.6	1.3	1.1	0.9	0.7	0.6	0.5
10.0	*****	91.8	72.9	57.9	46.0	36.6	29.1	23.1	18.4	14.6	11.6	9.2	7.4	5.9	4.7	3.7	3.0	2.4	1.9	1.5	1.2	1.0	0.8	0.6	0.5	0.4
11.0	*****	84.9	67.4	53.6	42.6	33.8	26.9	21.4	17.0	13.5	10.7	8.5	6.8	5.4	4.3	3.4	2.7	2.2	1.8	1.4	1.1	0.9	0.7	0.6	0.5	0.4
12.0	98.9	78.5	62.4	49.6	39.4	31.3	24.9	19.8	15.7	12.5	9.9	7.9	6.3	5.0	4.0	3.2	2.5	2.0	1.6	1.3	1.1	0.9	0.7	0.6	0.5	0.4
13.0	91.5	72.7	57.8	45.9	36.5	29.0	23.0	18.3	14.6	11.6	9.2	7.3	5.8	4.7	3.7	3.0	2.4	1.9	1.5	1.2	1.0	0.8	0.6	0.5	0.4	0.4
14.0	84.8	67.4	53.5	42.5	33.8	26.9	21.4	17.0	13.5	10.7	8.5	6.8	5.4	4.3	3.4	2.7	2.2	1.8	1.4	1.1	0.9	0.7	0.6	0.5	0.4	0.3
15.0	78.6	62.5	49.6	39.4	31.3	24.9	19.8	15.7	12.5	10.0	7.9	6.3	5.0	4.0	3.2	2.6	2.0	1.6	1.3	1.1	0.9	0.7	0.6	0.5	0.4	0.3
16.0	72.9	57.9	46.0	36.6	29.1	23.1	18.4	14.6	11.6	9.2	7.4	5.9	4.7	3.7	3.0	2.4	1.9	1.5	1.2	1.0	0.8	0.6	0.5	0.4	0.4	0.3
17.0	67.6	53.7	42.7	33.9	27.0	21.4	17.0	13.6	10.8	6.6	6.8	5.4	4.3	3.5	2.8	2.2	1.8	1.4	1.1	0.9	0.7	0.6	0.5	0.4	0.3	0.3
18.0	62.8	49.9	39.6	31.5	25.0	19.9	15.8	12.6	10.0	8.0	6.3	5.1	4.0	3.2	2.6	2.1	1.6	1.3	1.1	0.9	0.7	0.6	0.5	0.4	0.3	0.3
19.0	58.3	46.3	36.8	29.3	23.3	18.5	14.7	11.7	9.3	7.4	5.9	4.7	3.7	3.0	2.4	1.9	1.5	1.2	1.0	0.8	0.7	0.5	0.4	0.4	0.3	0.3
20.0	54.2	43.1	34.2	27.2	21.6	17.2	13.7	10.9	8.6	6.9	5.5	4.4	3.5	2.8	2.2	1.8	1.4	1.1	0.9	0.7	0.6	0.5	0.4	0.3	0.3	0.2
21.0	50.4	40.0	31.8	25.3	20.1	16.0	12.7	10.1	8.0	6.4	5.1	4.1	3.2	2.6	2.1	1.7	1.3	1.1	0.9	0.7	0.6	0.5	0.4	0.3	0.3	0.2
22.0	46.9	37.3	29.6	23.5	18.7	14.9	11.8	9.4	7.5	6.0	4.7	3.8	3.0	2.4	1.9	1.5	1.2	1.0	0.8	0.7	0.5	0.4	0.4	0.3	0.3	0.2
23.0	43.6	34.7	27.6	21.9	17.4	13.8	11.0	8.8	7.0	5.6	4.4	3.5	2.8	2.3	1.8	1.4	1.2	0.9	0.8	0.6	0.5	0.4	0.3	0.3	0.2	0.2
24.0	40.6	32.3	25.7	20.4	16.2	12.9	10.3	8.2	6.5	5.2	4.1	3.3	2.6	2.1	1.7	1.4	1.1	0.9	0.7	0.6	0.5	0.4	0.3	0.3	0.2	0.2
25.0	37.9	30.1	23.9	19.0	15.1	12.0	9.6	7.6	6.1	4.8	3.8	3.1	2.5	2.0	1.6	1.3	1.0	0.8	0.7	0.5	0.4	0.4	0.3	0.3	0.2	0.2

Table B4.2. Ammonia effluent limits for the City of Fort Collins based on actual effluent flows, 7Q10 and 30Q10 chronic design flows and an instream ammonia standard of 0.06 mg/l-N.

DISCHARGER: FORT COLLINS STREAM: CACHE LA POUDRE
UPSTREAM FLOW IN CFS: 1.4
UPSTREAM AMMONIA IN mg/l: 0.0
UN-IONIZED AMMONIA STANDARD IN mg/l X 10 0.6
DISCHARGE FLOW IN MGD: 4.7

DEGREES CENTIGRADE	pH 6.5	6.6	6.7	6.8	6.9	7.0	7.1	7.2	7.3	7.4	7.5	7.6	7.7	7.8	7.9	8.0	8.1	8.2	8.3	8.4	8.5	8.6	8.7	8.8	8.9	9.0
3.0	*****	*****	*****	*****	85.3	67.8	53.6	42.8	34.0	27.0	21.5	17.1	13.6	10.8	8.6	6.8	5.4	4.3	3.5	2.8	2.2	1.8	1.4	1.1	0.9	0.7
4.0	*****	*****	*****	98.9	78.6	62.4	49.6	39.4	31.3	24.9	19.8	15.7	12.5	10.0	7.9	6.3	5.0	4.0	3.2	2.6	2.0	1.6	1.3	1.1	0.9	0.7
5.0	*****	*****	*****	91.1	72.4	57.5	45.7	36.3	28.9	22.9	18.2	14.5	11.5	9.2	7.3	5.8	4.6	3.7	3.0	2.4	1.9	1.5	1.2	1.0	0.8	0.6
6.0	*****	*****	*****	84.1	66.8	53.1	42.2	33.5	26.6	21.2	16.8	13.4	10.6	8.5	6.7	5.4	4.3	3.4	2.7	2.2	1.7	1.4	1.1	0.9	0.7	0.6
7.0	*****	*****	97.6	77.6	61.6	49.0	38.9	30.9	24.6	19.5	15.5	12.4	9.8	7.8	6.2	5.0	4.0	3.2	2.5	2.0	1.6	1.3	1.0	0.8	0.7	0.6
8.0	*****	*****	90.2	71.6	56.9	45.2	35.9	28.6	22.7	18.0	14.3	11.4	9.1	7.2	5.8	4.6	3.7	2.9	2.3	1.9	1.5	1.2	1.0	0.8	0.6	0.5
9.0	*****	*****	83.3	66.2	52.6	41.8	33.2	26.4	21.0	16.7	13.3	10.5	8.4	6.7	5.3	4.2	3.4	2.7	2.2	1.7	1.4	1.1	0.9	0.7	0.5	0.5
10.0	*****	96.9	77.0	61.2	48.6	38.6	30.7	24.4	19.4	15.4	12.3	9.8	7.8	6.2	4.9	3.9	3.1	2.5	2.0	1.6	1.3	1.0	0.8	0.7	0.6	0.5
11.0	*****	89.6	71.2	56.6	45.0	35.7	28.4	22.6	17.9	14.3	11.3	9.0	7.2	5.7	4.6	3.6	2.9	2.3	1.9	1.5	1.2	1.0	0.8	0.6	0.5	0.4
12.0	*****	82.9	65.9	52.4	41.6	33.1	26.3	20.9	16.6	13.2	10.5	8.4	6.7	5.3	4.2	3.4	2.7	2.2	1.7	1.4	1.1	0.9	0.7	0.6	0.5	0.4
13.0	96.7	76.8	61.0	48.5	38.5	30.6	24.3	19.3	15.4	12.2	9.7	7.7	6.2	4.9	3.9	3.1	2.5	2.0	1.6	1.3	1.0	0.8	0.7	0.6	0.5	0.4
14.0	89.6	71.2	56.5	44.9	35.7	28.4	22.5	17.9	14.3	11.3	9.0	7.2	5.7	4.5	3.6	2.9	2.3	1.9	1.5	1.2	1.0	0.8	0.6	0.5	0.4	0.4
15.0	83.0	66.0	52.4	41.6	33.1	26.3	20.9	16.6	13.2	10.5	8.4	6.7	5.3	4.2	3.4	2.7	2.2	1.7	1.4	1.1	0.9	0.7	0.6	0.5	0.4	0.3
16.0	77.0	61.2	48.6	38.6	30.7	24.4	19.4	15.4	12.3	9.8	7.8	6.2	4.9	3.9	3.1	2.5	2.0	1.6	1.3	1.0	0.8	0.7	0.6	0.5	0.4	0.3
17.0	71.4	56.8	45.1	35.8	28.5	22.6	18.0	14.3	11.4	9.1	7.2	5.7	4.6	3.6	2.9	2.3	1.9	1.5	1.2	1.0	0.8	0.6	0.5	0.4	0.4	0.3
18.0	66.3	52.7	41.9	33.3	26.4	21.0	16.7	13.3	10.6	8.4	6.7	5.3	4.3	3.4	2.7	2.2	1.7	1.4	1.1	0.9	0.7	0.6	0.5	0.4	0.3	0.3
19.0	61.6	48.9	38.9	30.9	24.6	19.5	15.5	12.3	9.8	7.8	6.2	5.0	4.0	3.2	2.5	2.0	1.6	1.3	1.0	0.8	0.7	0.6	0.5	0.4	0.3	0.3
20.0	57.2	45.5	36.1	28.7	22.8	18.2	14.4	11.5	9.1	7.3	5.8	4.6	3.7	2.9	2.3	1.9	1.5	1.2	1.0	0.8	0.6	0.5	0.4	0.4	0.3	0.3
21.0	53.2	42.3	33.6	26.7	21.2	16.9	13.4	10.7	8.5	6.8	5.4	4.3	3.4	2.7	2.2	1.8	1.4	1.1	0.9	0.7	0.6	0.5	0.4	0.3	0.3	0.2
22.0	49.5	39.3	31.3	24.8	19.8	15.7	12.5	9.9	7.9	6.3	5.0	4.0	3.2	2.5	2.0	1.6	1.3	1.1	0.9	0.7	0.6	0.5	0.4	0.3	0.3	0.2
23.0	46.1	36.5	29.1	23.1	18.4	14.6	11.6	9.3	7.4	5.9	4.7	3.7	3.0	2.4	1.9	1.5	1.2	1.0	0.8	0.7	0.5	0.4	0.4	0.3	0.3	0.2
24.0	42.9	34.1	27.1	21.5	17.1	13.6	10.8	8.6	6.9	5.5	4.4	3.5	2.8	2.2	1.8	1.4	1.1	0.9	0.8	0.6	0.5	0.4	0.3	0.3	0.2	0.2
25.0	40.0	31.8	25.2	20.1	15.9	12.7	10.1	8.0	6.4	5.1	4.1	3.2	2.6	2.1	1.7	1.3	1.1	0.9	0.7	0.6	0.5	0.4	0.3	0.3	0.2	0.2

Table B4.3. Ammonia effluent limits for the City of Fort Collins based on a 30Q3 chronic design flow and an instream ammonia standard of 0.06 mg/l-N.

DISCHARGER: FORT COLLINS STREAM: CACHE LA POUDRE
UPSTREAM FLOW IN CFS: 2.9
UPSTREAM AMMONIA IN mg/l: 0.0
UN-IONIZED AMMONIA STANDARD IN mg/l X 10 0.6
DISCHARGE FLOW IN MGD: 7.0

DEGREES CENTIGRADE	pH 6.5	6.6	6.7	6.8	6.9	7.0	7.1	7.2	7.3	7.4	7.5	7.6	7.7	7.8	7.9	8.0	8.1	8.2	8.3	8.4	8.5	8.6	8.7	8.8	8.9	9.0
3.0	*****	*****	*****	*****	90.7	72.0	57.2	45.5	36.1	28.7	22.8	18.1	14.4	11.5	9.1	7.3	5.8	4.6	3.7	2.9	2.4	1.9	1.5	1.2	1.0	0.8
4.0	*****	*****	*****	*****	83.5	66.4	52.7	41.9	33.3	26.5	21.0	16.7	13.3	10.6	8.4	6.7	5.3	4.3	3.4	2.7	2.2	1.7	1.4	1.1	0.9	0.7
5.0	*****	*****	*****	96.9	77.0	61.2	48.6	38.6	30.7	24.4	19.4	15.4	12.3	9.8	7.8	6.2	4.9	3.9	3.1	2.5	2.0	1.6	1.3	1.0	0.8	0.7
6.0	*****	*****	*****	89.4	71.0	56.4	44.8	35.6	28.3	22.5	17.9	14.2	11.3	9.0	7.2	5.7	4.6	3.6	2.9	2.3	1.9	1.5	1.2	1.0	0.8	0.6
7.0	*****	*****	*****	82.5	65.5	52.1	41.4	32.9	26.1	20.8	16.5	13.1	10.4	8.3	6.6	5.3	4.2	3.4	2.7	2.1	1.7	1.4	1.1	0.9	0.7	0.6
8.0	*****	*****	95.8	76.1	60.5	48.1	38.2	30.4	24.1	19.2	15.3	12.1	9.7	7.7	6.1	4.9	3.9	3.1	2.5	2.0	1.6	1.3	1.0	0.8	0.7	0.6
9.0	*****	*****	88.5	70.4	55.9	44.4	35.3	28.1	22.3	17.7	14.1	11.2	8.9	7.1	5.7	4.5	3.6	2.9	2.3	1.8	1.5	1.2	1.0	0.8	0.6	0.5
10.0	*****	*****	81.9	65.0	51.7	41.1	32.6	25.9	20.6	16.4	13.0	10.4	8.3	6.6	5.2	4.2	3.3	2.7	2.1	1.7	1.4	1.1	0.9	0.7	0.6	0.5
11.0	*****	95.3	75.7	60.2	47.8	38.0	30.2	24.0	19.1	15.2	12.1	9.6	7.6	6.1	4.8	3.9	3.1	2.5	2.0	1.6	1.3	1.0	0.8	0.7	0.6	0.5
12.0	*****	88.2	70.1	55.7	44.2	35.2	27.9	22.2	17.7	14.0	11.2	8.9	7.1	5.6	4.5	3.6	2.9	2.3	1.8	1.5	1.2	1.0	0.8	0.6	0.5	0.4
13.0	*****	81.7	64.9	51.5	41.0	32.6	25.9	20.6	16.4	13.0	10.3	8.2	6.6	5.2	4.2	3.3	2.7	2.1	1.7	1.4	1.1	0.9	0.7	0.6	0.5	0.4
14.0	95.2	75.6	60.1	47.8	37.9	30.2	24.0	19.1	15.2	12.1	9.6	7.6	6.1	4.8	3.9	3.1	2.5	2.0	1.6	1.3	1.0	0.8	0.7	0.6	0.5	0.4
15.0	88.3	70.1	55.7	44.3	35.2	28.0	22.2	17.7	14.1	11.2	8.9	7.1	5.6	4.5	3.6	2.9	2.3	1.8	1.5	1.2	1.0	0.8	0.6	0.5	0.4	0.4
16.0	81.8	65.0	51.7	41.1	32.6	25.9	20.6	16.4	13.0	10.4	8.3	6.6	5.2	4.2	3.3	2.7	2.1	1.7	1.4	1.1	0.9	0.7	0.6	0.5	0.4	0.3
17.0	75.9	60.3	47.9	38.1	30.3	24.1	19.1	15.2	12.1	9.6	7.7	6.1	4.9	3.9	3.1	2.5	2.0	1.6	1.3	1.0	0.8	0.7	0.6	0.5	0.4	0.3
18.0	70.5	56.0	44.5	35.4	28.1	22.3	17.8	14.1	11.2	8.9	7.1	5.7	4.5	3.6	2.9	2.3	1.8	1.5	1.2	1.0	0.8	0.6	0.5	0.4	0.4	0.3
19.0	65.5	52.0	41.3	32.9	26.1	20.8	16.5	13.1	10.4	8.3	6.6	5.3	4.2	3.4	2.7	2.1	1.7	1.4	1.1	0.9	0.7	0.6	0.5	0.4	0.3	0.3
20.0	60.9	48.4	38.4	30.5	24.3	19.3	15.3	12.2	9.7	7.7	6.2	4.9	3.9	3.1	2.5	2.0	1.6	1.3	1.0	0.8	0.7	0.6	0.5	0.4	0.3	0.3
21.0	56.6	45.0	35.7	28.4	22.6	17.9	14.3	11.4	9.0	7.2	5.7	4.6	3.6	2.9	2.3	1.9	1.5	1.2	1.0	0.8	0.6	0.5	0.4	0.4	0.3	0.3
22.0	52.6	41.8	33.2	26.4	21.0	16.7	13.3	10.6	8.4	6.7	5.3	4.3	3.4	2.7	2.2	1.7	1.4	1.1	0.9	0.7	0.6	0.5	0.4	0.3	0.3	0.2
23.0	49.0	38.9	30.9	24.6	19.5	15.5	12.4	9.8	7.8	6.2	5.0	4.0	3.2	2.5	2.0	1.6	1.3	1.1	0.9	0.7	0.6	0.5	0.4	0.3	0.3	0.2
24.0	45.6	36.2	28.8	22.9	18.2	14.5	11.5	9.2	7.3	5.8	4.6	3.7	2.9	2.4	1.9	1.5	1.2	1.0	0.8	0.6	0.5	0.4	0.4	0.3	0.3	0.2
25.0	42.5	33.8	26.8	21.3	17.0	13.5	10.7	8.5	6.8	5.4	4.3	3.4	2.8	2.2	1.8	1.4	1.1	0.9	0.7	0.6	0.5	0.4	0.3	0.3	0.2	0.2

Table B4.4. Ammonia effluent limits for the City of Fort Collins based on 7Q10 and 30Q10 chronic design flows and an instream ammonia standard of 0.10 mg/l-N.

DISCHARGER: FORT COLLINS STREAM: CACHE LA POUDRE
UPSTREAM FLOW IN CFS: 1.4
UPSTREAM AMMONIA IN mg/l: 0.0
UN-IONIZED AMMONIA STANDARD IN mg/l X 10 1.0
DISCHARGE FLOW IN MGD: 7.0

DEGREES CENTIGRADE	pH																									
	6.5	6.6	6.7	6.8	6.9	7.0	7.1	7.2	7.3	7.4	7.5	7.6	7.7	7.8	7.9	8.0	8.1	8.2	8.3	8.4	8.5	8.6	8.7	8.8	8.9	9.0
3.0	*****	*****	*****	*****	*****	*****	85.0	67.5	53.6	42.6	33.9	26.9	21.4	17.0	13.6	10.8	8.6	6.9	5.5	4.4	3.5	2.8	2.2	1.8	1.5	1.2
4.0	*****	*****	*****	*****	*****	98.5	78.3	62.2	49.4	39.3	31.2	24.8	19.7	15.7	12.5	10.0	7.9	6.3	5.0	4.0	3.2	2.6	2.1	1.7	1.4	1.1
5.0	*****	*****	*****	*****	*****	90.8	72.1	57.3	45.6	36.2	28.8	22.9	18.2	14.5	11.5	9.2	7.3	5.8	4.7	3.7	3.0	2.4	1.9	1.6	1.3	1.0
6.0	*****	*****	*****	*****	*****	83.7	66.5	52.9	42.0	33.4	26.6	21.1	16.8	13.4	10.6	8.5	6.8	5.4	4.3	3.4	2.8	2.2	1.8	1.4	1.2	0.9
7.0	*****	*****	*****	*****	97.3	77.3	61.4	48.8	38.8	30.8	24.5	19.5	15.5	12.3	9.8	7.8	6.2	5.0	4.0	3.2	2.6	2.1	1.7	1.3	1.1	0.9
8.0	*****	*****	*****	*****	89.8	71.4	56.7	45.1	35.8	28.5	22.6	18.0	14.3	11.4	9.1	7.2	5.8	4.6	3.7	2.9	2.4	1.9	1.5	1.2	1.0	0.8
9.0	*****	*****	*****	*****	83.0	65.9	52.4	41.6	33.1	26.3	20.9	16.6	13.2	10.5	8.4	6.7	5.3	4.3	3.4	2.7	2.2	1.8	1.4	1.2	0.9	0.8
10.0	*****	*****	*****	96.5	76.7	61.0	48.4	38.5	30.6	24.3	19.4	15.4	12.3	9.8	7.8	6.2	4.9	4.0	3.2	2.5	2.0	1.6	1.3	1.1	0.9	0.7
11.0	*****	*****	*****	89.3	71.0	56.4	44.8	35.6	28.3	22.5	17.9	14.2	11.3	9.0	7.2	5.7	4.6	3.7	2.9	2.4	1.9	1.5	1.2	1.0	0.8	0.7
12.0	*****	*****	*****	82.6	65.7	52.2	41.5	33.0	26.2	20.8	16.6	13.2	10.5	8.4	6.7	5.3	4.2	3.4	2.7	2.2	1.8	1.4	1.2	0.9	0.8	0.6
13.0	*****	*****	96.3	76.5	60.8	48.3	38.4	30.5	24.3	19.3	15.4	12.2	9.7	7.8	6.2	4.9	3.9	3.2	2.5	2.0	1.6	1.3	1.1	0.9	0.7	0.6
14.0	*****	*****	89.2	70.9	56.3	44.8	35.6	28.3	22.5	17.9	14.2	11.3	9.0	7.2	5.7	4.6	3.7	2.9	2.4	1.9	1.5	1.2	1.0	0.8	0.7	0.6
15.0	*****	*****	82.7	65.7	52.2	41.5	33.0	26.2	20.9	16.6	13.2	10.5	8.4	6.7	5.3	4.3	3.4	2.7	2.2	1.8	1.4	1.2	0.9	0.8	0.6	0.5
16.0	*****	96.5	76.7	61.0	48.4	38.5	30.6	24.3	19.4	15.4	12.3	9.8	7.8	6.2	4.9	4.0	3.2	2.5	2.0	1.6	1.3	1.1	0.9	0.7	0.6	0.5
17.0	*****	89.6	71.2	56.6	44.9	35.7	28.4	22.6	18.0	14.3	11.4	9.1	7.2	5.8	4.6	3.7	2.9	2.4	1.9	1.5	1.2	1.0	0.8	0.7	0.6	0.5
18.0	*****	83.2	66.1	52.5	41.7	33.2	26.4	21.0	16.7	13.3	10.6	8.4	6.7	5.4	4.3	3.4	2.7	2.2	1.8	1.4	1.2	0.9	0.8	0.6	0.5	0.4
19.0	97.2	77.2	61.4	48.8	38.8	30.8	24.5	19.5	15.5	12.3	9.8	7.8	6.2	5.0	4.0	3.2	2.6	2.1	1.7	1.3	1.1	0.9	0.7	0.6	0.5	0.4
20.0	90.3	71.8	57.0	45.3	36.0	28.6	22.8	18.1	14.4	11.5	9.1	7.3	5.8	4.6	3.7	3.0	2.4	1.9	1.5	1.2	1.0	0.8	0.7	0.6	0.5	0.4
21.0	84.0	66.7	53.0	42.2	33.5	26.6	21.2	16.9	13.4	10.7	8.5	6.8	5.4	4.3	3.5	2.8	2.2	1.8	1.4	1.2	1.0	0.8	0.6	0.5	0.4	0.4
22.0	78.1	62.1	49.3	39.2	31.2	24.8	19.7	15.7	12.5	9.9	7.9	6.3	5.0	4.0	3.2	2.6	2.1	1.7	1.3	1.1	0.9	0.7	0.6	0.5	0.4	0.4
23.0	72.7	57.8	45.9	36.5	29.0	23.1	18.4	14.6	11.6	9.3	7.4	5.9	4.7	3.8	3.0	2.4	1.9	1.6	1.3	1.0	0.8	0.7	0.6	0.5	0.4	0.3
24.0	67.7	53.8	42.8	34.0	27.0	21.5	17.1	13.6	10.8	8.6	6.9	5.5	4.4	3.5	2.8	2.3	1.8	1.5	1.2	1.0	0.8	0.6	0.5	0.5	0.4	0.3
25.0	63.1	50.1	39.8	31.7	25.2	20.0	15.9	12.7	10.1	8.0	6.4	5.1	4.1	3.3	2.6	2.1	1.7	1.4	1.1	0.9	0.7	0.6	0.5	0.4	0.4	0.3

Table B4.5. Ammonia effluent limits for the City of Fort Collins based on a 30Q3 chronic design flow and an instream ammonia standard of 0.10 mg/l-N.

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DISCHARGER: FORT COLLINS          STREAM: CACHE LA POUDRE
UPSTREAM FLOW IN CFS:                       2.9
UPSTREAM AMMONIA IN mg/l:                   0.0
UN-IONIZED AMMONIA STANDARD IN mg/l X 10    1.0
DISCHARGE FLOW IN MGD:                      7.0

                                                                    pH
            6.5  6.6  6.7  6.8  6.9  7.0  7.1  7.2  7.3  7.4  7.5  7.6  7.7  7.8  7.9  8.0  8.1  8.2  8.3  8.4  8.5  8.6  8.7  8.8  8.9  9.0
DEGREES
CENTIGRADE
   3.0     *******************************95.4 75.8 60.2 47.9 38.0 30.2 24.1 19.1 15.2 12.1  9.7  7.7  6.1  4.9  3.9  3.1  2.5  2.0  1.6  1.3
   4.0     *******************************87.9 69.8 55.5 44.1 35.1 27.9 22.2 17.6 14.0 11.2  8.9  7.1  5.7  4.5  3.6  2.9  2.3  1.9  1.5  1.2
   5.0     *******************************81.0 64.4 51.2 40.7 32.3 25.7 20.4 16.3 12.9 10.3  8.2  6.6  5.2  4.2  3.3  2.7  2.2  1.7  1.4  1.1
   6.0     **************************94.0 74.7 59.4 47.2 37.5 29.8 23.7 18.9 15.0 11.9  9.5  7.6  6.1  4.8  3.9  3.1  2.5  2.0  1.6  1.3  1.1
   7.0     **************************86.8 68.9 54.8 43.6 34.6 27.5 21.9 17.4 13.9 11.0  8.8  7.0  5.5  4.5  3.6  2.9  2.3  1.9  1.5  1.2  1.0
   8.0     **************************80.1 63.7 50.6 40.2 32.0 25.4 20.2 16.1 12.8 10.2  8.1  6.5  5.2  4.1  3.3  2.7  2.1  1.7  1.4  1.1  0.9
   9.0     *********************93.2 74.0 58.8 46.8 37.2 29.5 23.5 18.7 14.9 11.8  9.4  7.5  6.0  4.8  3.8  3.1  2.5  2.0  1.6  1.3  1.1  0.9
  10.0     *********************86.1 68.4 54.4 43.2 34.4 27.3 21.7 17.3 13.8 11.0  8.7  7.0  5.6  4.4  3.6  2.8  2.3  1.8  1.5  1.2  1.0  0.8
  11.0     *********************79.7 63.3 50.3 40.0 31.8 25.3 20.1 16.0 12.7 10.1  8.1  6.4  5.1  4.1  3.3  2.6  2.1  1.7  1.4  1.1  0.9  0.8
  12.0     ****************92.8 73.7 58.6 46.6 37.0 29.4 23.4 18.6 14.8 11.8  9.4  7.5  6.0  4.8  3.8  3.1  2.5  2.0  1.6  1.3  1.1  0.9  0.7
  13.0     ****************85.9 68.3 54.3 43.1 34.3 27.3 21.7 17.2 13.7 10.9  8.7  6.9  5.5  4.4  3.5  2.8  2.3  1.8  1.5  1.2  1.0  0.8  0.7
  14.0     ****************79.6 63.2 50.3 40.0 31.8 25.3 20.1 16.0 12.7 10.1  8.1  6.4  5.1  4.1  3.3  2.6  2.1  1.7  1.4  1.1  0.9  0.8  0.6
  15.0     ***********92.9 73.8 58.6 46.6 37.0 29.4 23.4 18.6 14.8 11.8  9.4  7.5  6.0  4.8  3.8  3.1  2.5  2.0  1.6  1.3  1.1  0.9  0.7  0.6
  16.0     ***********86.1 68.4 54.4 43.2 34.4 27.3 21.7 17.3 13.8 11.0  8.7  7.0  5.6  4.4  3.5  2.8  2.3  1.8  1.5  1.2  1.0  0.8  0.7  0.6
  17.0     ***********79.9 63.5 50.5 40.1 31.9 25.4 20.2 16.0 12.8 10.2  8.1  6.5  5.2  4.1  3.3  2.6  2.1  1.7  1.4  1.1  0.9  0.8  0.6  0.5
  18.0     ******93.4 74.2 59.0 46.9 37.2 29.6 23.5 18.7 14.9 11.9  9.5  7.5  6.0  4.8  3.8  3.1  2.5  2.0  1.6  1.3  1.1  0.9  0.7  0.6  0.5
  19.0     ******86.7 68.9 54.8 43.5 34.6 27.5 21.9 17.4 13.9 11.0  8.8  7.0  5.6  4.5  3.6  2.9  2.3  1.9  1.5  1.2  1.0  0.8  0.7  0.6  0.5
  20.0     ******80.6 64.0 50.9 40.5 32.2 25.6 20.3 16.2 12.9 10.3  8.2  6.5  5.2  4.2  3.3  2.7  2.1  1.7  1.4  1.1  0.9  0.8  0.6  0.5  0.4
  21.0      94.3 74.9 59.5 47.3 37.6 29.9 23.8 18.9 15.1 12.0  9.5  7.6  6.1  4.8  3.9  3.1  2.5  2.0  1.6  1.3  1.1  0.9  0.7  0.6  0.5  0.4
  22.0      87.7 69.7 55.4 44.0 35.0 27.8 22.1 17.6 14.0 11.2  8.9  7.1  5.7  4.5  3.6  2.9  2.3  1.9  1.5  1.2  1.0  0.8  0.7  0.6  0.5  0.4
  23.0      81.6 64.9 51.6 41.0 32.6 25.9 20.6 16.4 13.0 10.4  8.3  6.6  5.3  4.2  3.4  2.7  2.2  1.8  1.4  1.2  0.9  0.8  0.6  0.5  0.5  0.4
  24.0      76.0 60.4 48.0 38.2 30.3 24.1 19.2 15.3 12.2  9.7  7.7  6.2  4.9  3.9  3.1  2.5  2.0  1.6  1.3  1.1  0.9  0.7  0.6  0.5  0.4  0.4
  25.0      70.8 56.3 44.7 35.6 28.3 22.5 17.9 14.2 11.3  9.0  7.2  5.7  4.6  3.7  2.9  2.4  1.9  1.5  1.2  1.0  0.8  0.7  0.6  0.5  0.4  0.4
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Table B4.6. Ammonia effluent limits for the City of Fort Collins based on a 1Q10 acute design flow.

DISCHARGER: FORT COLLINS   STREAM: CACHE LA POUDRE
UPSTREAM FLOW IN CFS: 0.9
UPSTREAM AMMONIA IN mg/l: 0.0
UN-IONIZED AMMONIA STANDARD IN mg/l X 10 2.0
DISCHARGE FLOW IN MGD: 7.0

DEGREES CENTIGRADE	pH 6.5	6.6	6.7	6.8	6.9	7.0	7.1	7.2	7.3	7.4	7.5	7.6	7.7	7.8	7.9	8.0	8.1	8.2	8.3	8.4	8.5	8.6	8.7	8.8	8.9	9.0
3.0	*****	*****	*****	*****	*****	*****	*****	*****	*****	81.8	65.0	51.7	41.1	32.7	26.0	20.7	16.5	13.1	10.5	8.4	6.7	5.4	4.3	3.5	2.8	2.3
4.0	*****	*****	*****	*****	*****	*****	*****	*****	94.8	75.4	59.9	47.6	37.9	30.1	24.0	19.1	15.2	12.1	9.7	7.7	6.2	5.0	4.0	3.2	2.6	2.1
5.0	*****	*****	*****	*****	*****	*****	*****	*****	87.4	69.5	55.2	43.9	34.9	27.8	22.1	17.6	14.0	11.2	8.9	7.1	5.7	4.6	3.7	3.0	2.4	2.0
6.0	*****	*****	*****	*****	*****	*****	*****	*****	80.6	64.1	50.9	40.5	32.2	25.6	20.4	16.3	13.0	10.3	8.3	6.6	5.3	4.2	3.4	2.8	2.2	1.8
7.0	*****	*****	*****	*****	*****	*****	*****	93.6	74.4	59.2	47.0	37.4	29.8	23.7	18.9	15.0	12.0	9.6	7.6	6.1	4.9	3.9	3.2	2.6	2.1	1.7
8.0	*****	*****	*****	*****	*****	*****	*****	86.5	68.7	54.6	43.4	34.6	27.5	21.9	17.4	13.9	11.1	8.8	7.1	5.7	4.5	3.6	2.9	2.4	1.9	1.6
9.0	*****	*****	*****	*****	*****	*****	*****	79.9	63.5	50.5	40.1	31.9	25.4	20.2	16.1	12.8	10.2	8.2	6.5	5.2	4.2	3.4	2.7	2.2	1.8	1.5
10.0	*****	*****	*****	*****	*****	*****	92.9	73.9	58.7	46.7	37.1	29.5	23.5	16.7	14.9	11.9	9.5	7.6	6.1	4.9	3.9	3.1	2.5	2.1	1.7	1.4
11.0	*****	*****	*****	*****	*****	*****	86.0	68.3	54.3	43.2	34.4	27.3	21.8	17.3	13.8	11.0	8.8	7.0	5.6	4.5	3.6	2.9	2.4	1.9	1.6	1.3
12.0	*****	*****	*****	*****	*****	*****	79.6	63.2	50.3	40.0	31.8	25.3	20.1	16.0	12.8	10.2	8.2	6.5	5.2	4.2	3.4	2.7	2.2	1.8	1.5	1.2
13.0	*****	*****	*****	*****	*****	92.7	73.7	58.6	46.6	37.0	29.5	23.4	18.7	14.9	11.9	9.5	7.6	6.1	4.9	3.9	3.1	2.5	2.1	1.7	1.4	1.1
14.0	*****	*****	*****	*****	*****	85.9	68.3	54.3	43.2	34.3	27.3	21.7	17.3	13.8	11.0	8.8	7.0	5.6	4.5	3.6	2.9	2.4	1.9	1.6	1.3	1.1
15.0	*****	*****	*****	*****	*****	79.6	63.3	50.3	40.0	31.8	25.3	20.2	16.1	12.8	10.2	8.2	6.5	5.2	4.2	3.4	2.7	2.2	1.8	1.5	1.2	1.0
16.0	*****	*****	*****	*****	92.9	73.8	58.7	46.7	37.1	29.5	23.5	18.7	14.9	11.9	9.5	7.6	6.1	4.9	3.9	3.1	2.5	2.1	1.7	1.4	1.1	1.0
17.0	*****	*****	*****	*****	86.2	68.5	54.5	43.3	34.5	27.4	21.8	17.4	13.8	11.0	8.8	7.0	5.6	4.5	3.6	2.9	2.4	1.9	1.6	1.3	1.1	0.9
18.0	*****	*****	*****	*****	80.1	63.6	50.6	40.2	32.0	25.5	20.3	16.1	12.9	10.3	8.2	6.6	5.3	4.2	3.4	2.7	2.2	1.8	1.5	1.2	1.0	0.9
19.0	*****	*****	*****	93.6	74.4	59.1	47.0	37.4	29.7	23.7	18.8	15.0	12.0	9.6	7.6	6.1	4.9	3.9	3.2	2.6	2.1	1.7	1.4	1.2	1.0	0.8
20.0	*****	*****	*****	87.0	69.1	54.9	43.7	34.8	27.6	22.0	17.5	14.0	11.1	8.9	7.1	5.7	4.6	3.7	3.0	2.4	1.9	1.6	1.3	1.1	0.9	0.8
21.0	*****	*****	*****	80.9	64.3	51.1	40.6	32.3	25.7	20.5	16.3	13.0	10.4	8.3	6.6	5.3	4.3	3.4	2.8	2.2	1.8	1.5	1.2	1.0	0.9	0.7
22.0	*****	*****	94.7	75.2	59.8	47.5	37.8	30.1	23.9	19.1	15.2	12.1	9.7	7.7	6.2	4.9	4.0	3.2	2.6	2.1	1.7	1.4	1.2	1.0	0.8	0.7
23.0	*****	*****	88.1	70.0	55.7	44.3	35.2	28.0	22.3	17.8	14.1	11.3	9.0	7.2	5.8	4.6	3.7	3.0	2.4	2.0	1.6	1.3	1.1	0.9	0.8	0.7
24.0	*****	*****	82.0	65.2	51.8	41.2	32.8	26.1	20.8	16.5	13.2	10.5	8.4	6.7	5.4	4.3	3.5	2.8	2.3	1.8	1.5	1.2	1.0	0.9	0.7	0.6
25.0	*****	95.2	76.4	60.8	48.3	38.4	30.6	24.3	19.4	15.4	12.3	9.8	7.8	6.3	5.0	4.0	3.3	2.6	2.1	1.7	1.4	1.2	1.0	0.8	0.7	0.6

Table B4.7. Ammonia effluent limits for the City of Fort Collins based on a 1Q3 acute design flow.

```
DISCHARGER:   Fort Collins          STREAM:   Cache la Poudre
UPSTREAM FLOW IN CFS:                          1.5
UPSTREAM AMMONIA IN mg/l:                      0.0
UN-IONIZED AMMONIA STANDARD IN mg/l X 10       2.0
DISCHARGE FLOW IN MGD:                         7.0
```

DEGREES CENTIGRADE	pH 6.5	6.6	6.7	6.8	6.9	7.0	7.1	7.2	7.3	7.4	7.5	7.6	7.7	7.8	7.9	8.0	8.1	8.2	8.3	8.4	8.5	8.6	8.7	8.8	8.9	9.0
3.0	*****	*****	*****	*****	*****	*****	*****	*****	*****	86.0	68.3	54.3	43.2	34.4	27.3	21.8	17.3	13.8	11.0	8.8	7.0	5.6	4.5	3.6	2.9	2.4
4.0	*****	*****	*****	*****	*****	*****	*****	*****	99.7	79.2	63.0	50.1	39.8	31.7	25.2	20.1	16.0	12.7	10.2	8.1	6.5	5.2	4.2	3.4	2.7	2.2
5.0	*****	*****	*****	*****	*****	*****	*****	*****	91.9	73.0	58.1	46.2	36.7	29.2	23.2	18.5	14.9	11.8	9.4	7.5	6.0	4.8	3.9	3.1	2.5	2.1
6.0	*****	*****	*****	*****	*****	*****	*****	*****	84.7	67.4	53.6	42.6	33.9	27.0	21.5	17.1	13.6	10.9	8.7	6.9	5.6	4.5	3.6	2.9	2.4	1.9
7.0	*****	*****	*****	*****	*****	*****	*****	98.4	78.2	62.2	49.4	39.3	31.3	24.9	19.8	15.8	12.6	10.0	8.0	6.4	5.1	4.1	3.3	2.7	2.2	1.8
8.0	*****	*****	*****	*****	*****	*****	*****	90.3	72.2	57.4	45.7	36.3	28.9	23.0	18.3	14.6	11.6	9.3	7.4	5.9	4.8	3.8	3.1	2.5	2.0	1.7
9.0	*****	*****	*****	*****	*****	*****	*****	84.0	66.8	53.1	42.2	33.6	26.7	21.3	16.9	13.5	10.8	8.6	6.9	5.5	4.4	3.6	2.9	2.3	1.9	1.6
10.0	*****	*****	*****	*****	*****	*****	97.7	77.6	61.7	49.1	39.0	31.0	24.7	19.7	15.7	12.5	10.0	8.0	6.4	5.1	4.1	3.3	2.7	2.2	1.8	1.5
11.0	*****	*****	*****	*****	*****	*****	90.4	71.8	57.1	45.4	36.1	28.7	22.8	18.2	14.5	11.5	9.2	7.4	5.9	4.7	3.8	3.1	2.5	2.0	1.7	1.4
12.0	*****	*****	*****	*****	*****	*****	83.6	66.5	52.9	42.0	33.4	26.6	21.2	16.9	13.4	10.7	8.6	6.8	5.5	4.4	3.5	2.9	2.3	1.9	1.5	1.3
13.0	*****	*****	*****	*****	*****	97.4	77.4	61.6	48.9	38.9	31.0	24.6	19.6	15.6	12.5	9.9	7.9	6.4	5.1	4.1	3.3	2.7	2.2	1.8	1.5	1.2
14.0	*****	*****	*****	*****	*****	90.3	71.8	57.0	45.4	36.1	28.7	22.8	18.2	14.5	11.6	9.2	7.4	5.9	4.7	3.8	3.1	2.5	2.0	1.7	1.4	1.1
15.0	*****	*****	*****	*****	*****	83.7	66.5	52.9	42.1	33.5	26.6	21.2	16.9	13.5	10.7	8.6	6.9	5.5	4.4	3.6	2.9	2.3	1.9	1.5	1.3	1.1
16.0	*****	*****	*****	*****	97.7	77.6	61.7	49.1	39.0	31.0	24.7	19.7	15.7	12.5	10.0	8.0	6.4	5.1	4.1	3.3	2.7	2.2	1.8	1.5	1.2	1.0
17.0	*****	*****	*****	*****	90.6	72.0	57.3	45.5	36.2	28.8	22.9	18.2	14.5	11.6	9.3	7.4	5.9	4.7	3.8	3.1	2.5	2.0	1.7	1.4	1.1	0.9
18.0	*****	*****	*****	*****	84.2	66.9	53.2	42.3	33.6	26.8	21.3	17.0	13.5	10.8	8.6	6.9	5.5	4.4	3.6	2.9	2.3	1.9	1.5	1.3	1.1	0.9
19.0	*****	*****	*****	98.4	78.2	62.1	49.4	39.3	31.3	24.9	19.8	15.8	12.6	10.0	8.0	6.4	5.1	4.1	3.3	2.7	2.2	1.8	1.5	1.2	1.0	0.8
20.0	*****	*****	*****	91.4	72.7	57.8	45.9	36.5	29.1	23.1	18.4	14.7	11.7	9.3	7.5	6.0	4.8	3.9	3.1	2.5	2.0	1.7	1.4	1.1	1.0	0.8
21.0	*****	*****	*****	85.0	67.6	53.7	42.7	34.0	27.0	21.5	17.1	13.7	10.9	8.7	7.0	5.6	4.5	3.6	2.9	2.4	1.9	1.6	1.3	1.1	0.9	0.8
22.0	*****	*****	99.5	79.1	62.9	50.0	39.7	31.6	25.2	20.0	16.0	12.7	10.2	8.1	6.5	5.2	4.2	3.4	2.7	2.2	1.8	1.5	1.2	1.0	0.9	0.7
23.0	*****	*****	92.6	73.6	58.5	46.5	37.0	29.4	23.4	18.7	14.9	11.9	9.5	7.6	6.1	4.9	3.9	3.1	2.5	2.1	1.7	1.4	1.2	1.0	0.8	0.7
24.0	*****	*****	86.2	68.5	54.5	43.3	34.5	27.4	21.8	17.4	13.9	11.1	8.8	7.1	5.7	4.5	3.7	2.9	2.4	1.9	1.6	1.3	1.1	0.9	0.8	0.7
25.0	*****	*****	80.3	63.9	50.8	40.4	32.1	25.6	20.4	16.2	12.9	10.3	8.2	6.6	5.2	4.2	3.4	2.8	2.2	1.8	1.5	1.2	1.0	0.8	0.7	0.6

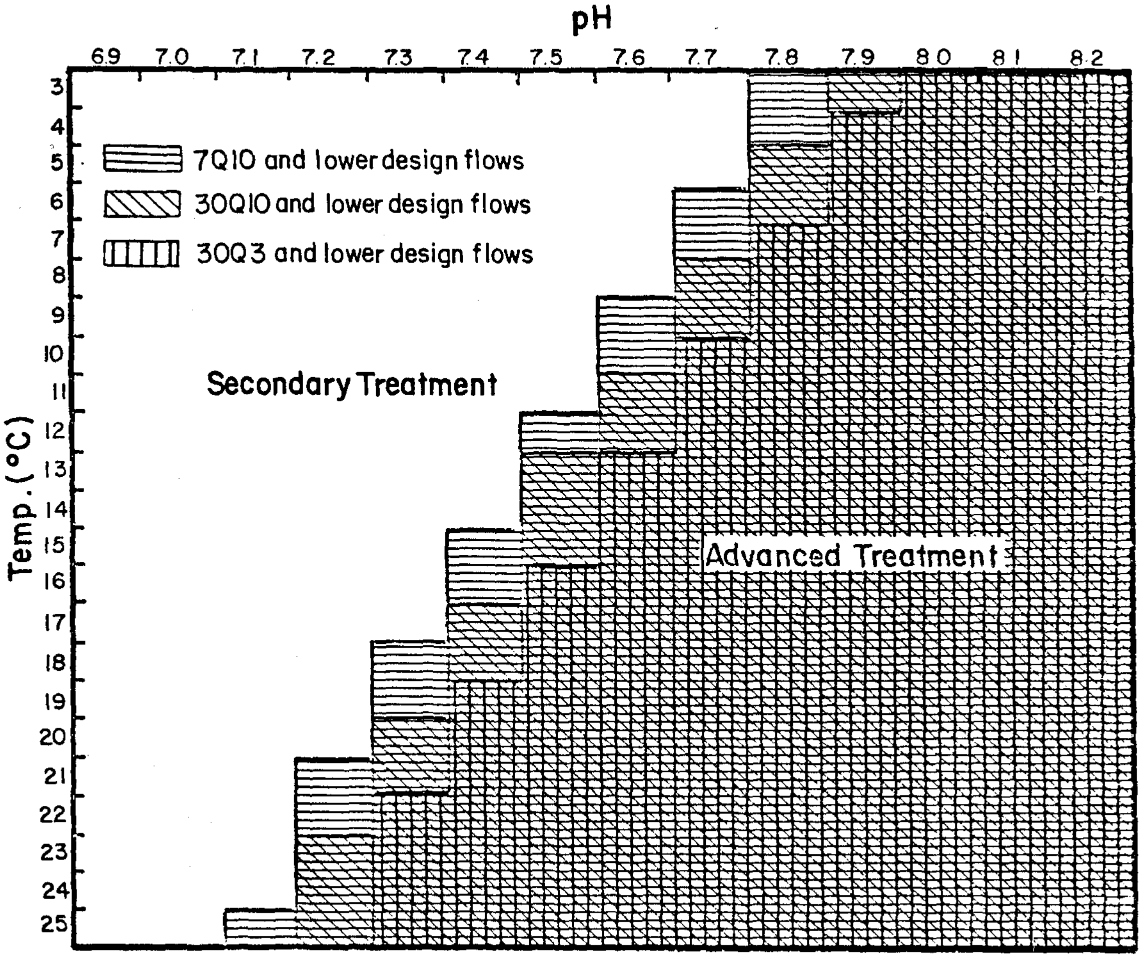

Figure B1.1 Ammonia treatment requirements for Englewood based on chronic design flows and a chronic instream ammonia standard of 0.06 mg/l-N.

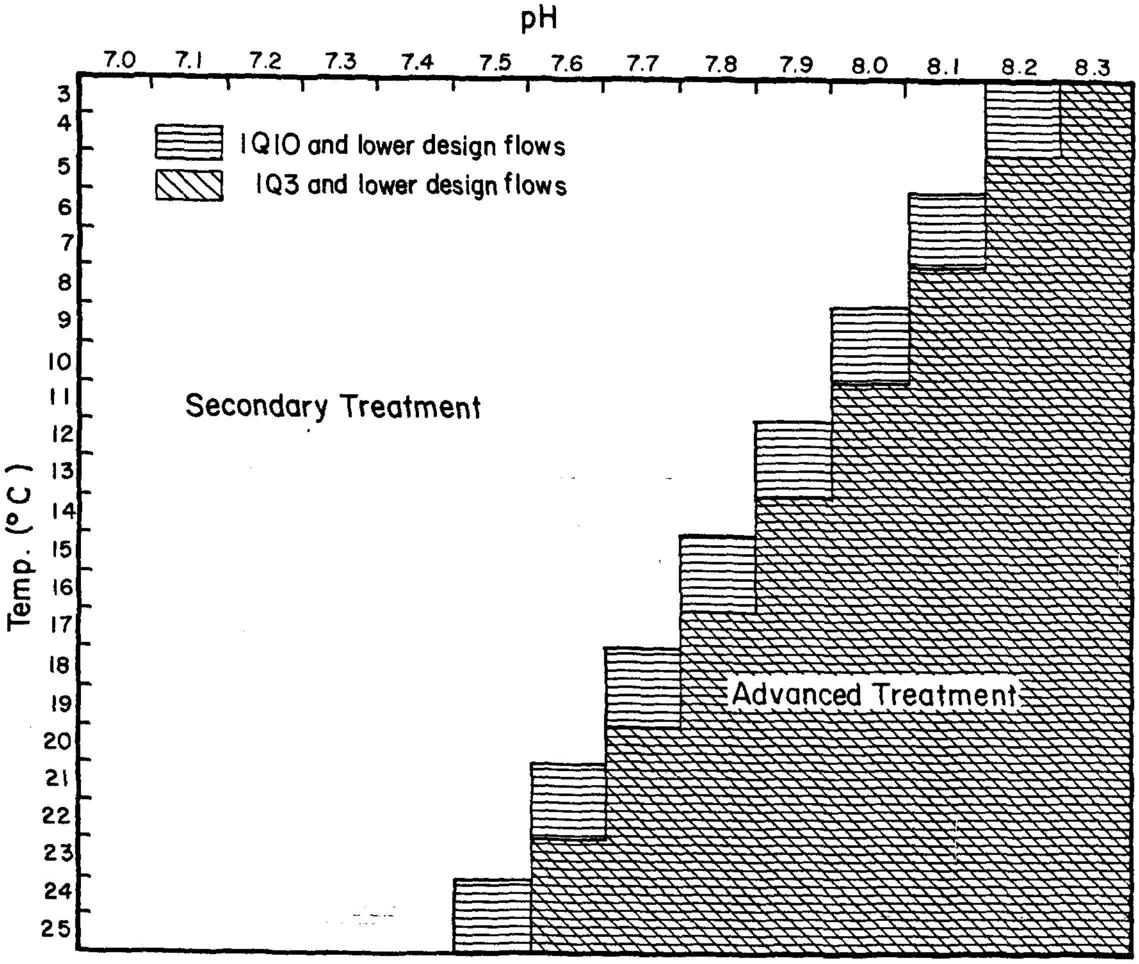

Figure B1.2 Ammonia treatment requirements for the City of Boulder based on chronic design flows and an instream ammonia standard of 0.06 mg/l-N.

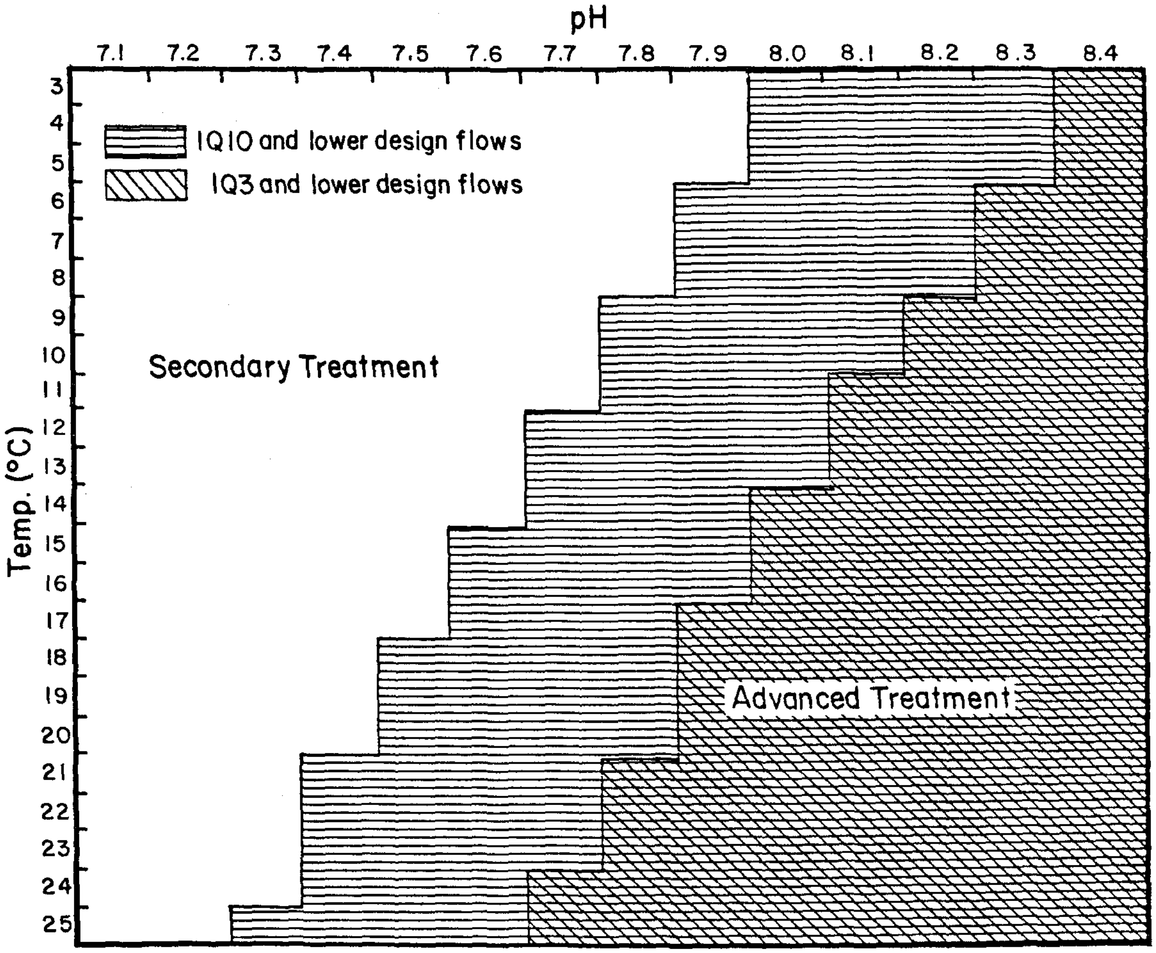

Figure B1.3 Ammonia treatment requirements for the City of Longmont based on chronic design flows and an instream ammonia standard of 0.06 mg/l-N.

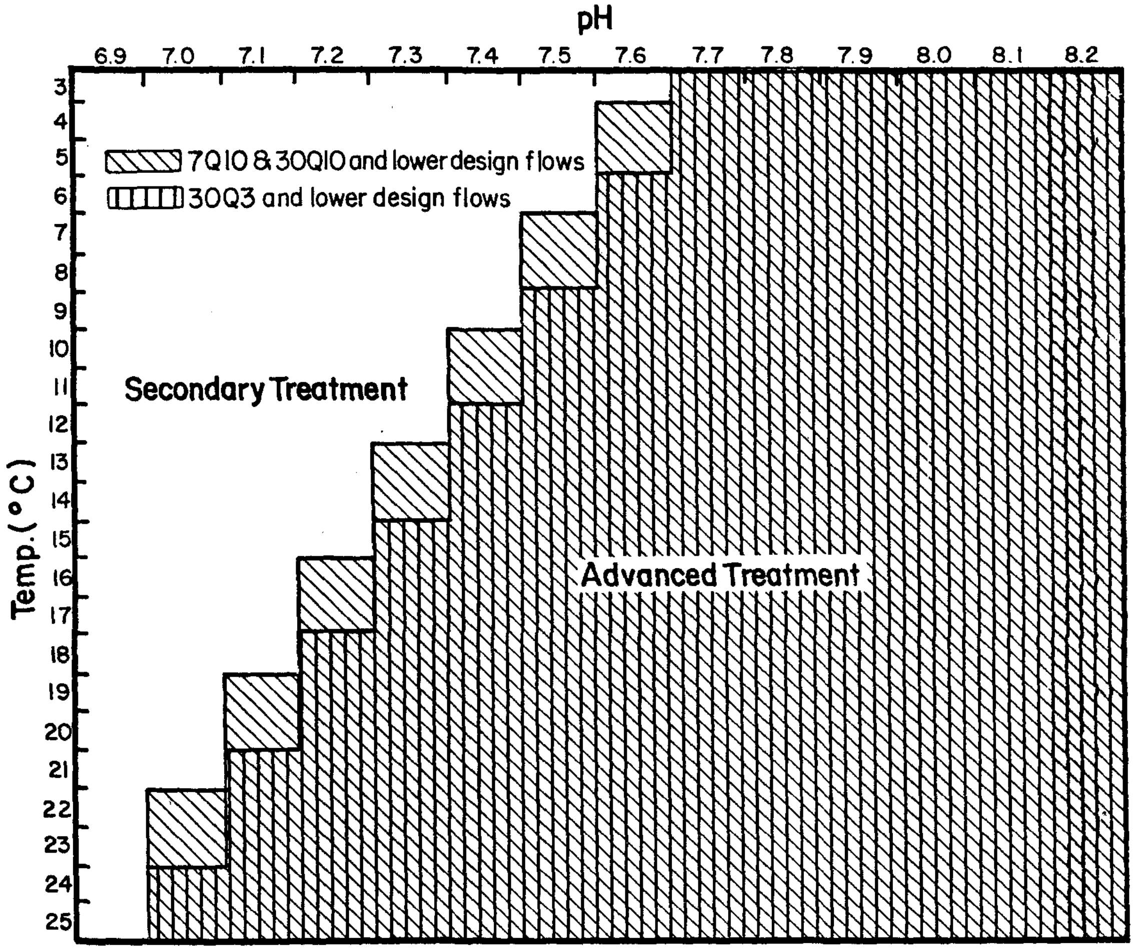

Figure B1.4 Ammonia treatment requirements for the City of Fort Collins based on chronic design flows and an instream ammonia standard of 0.06 mg/l-N.

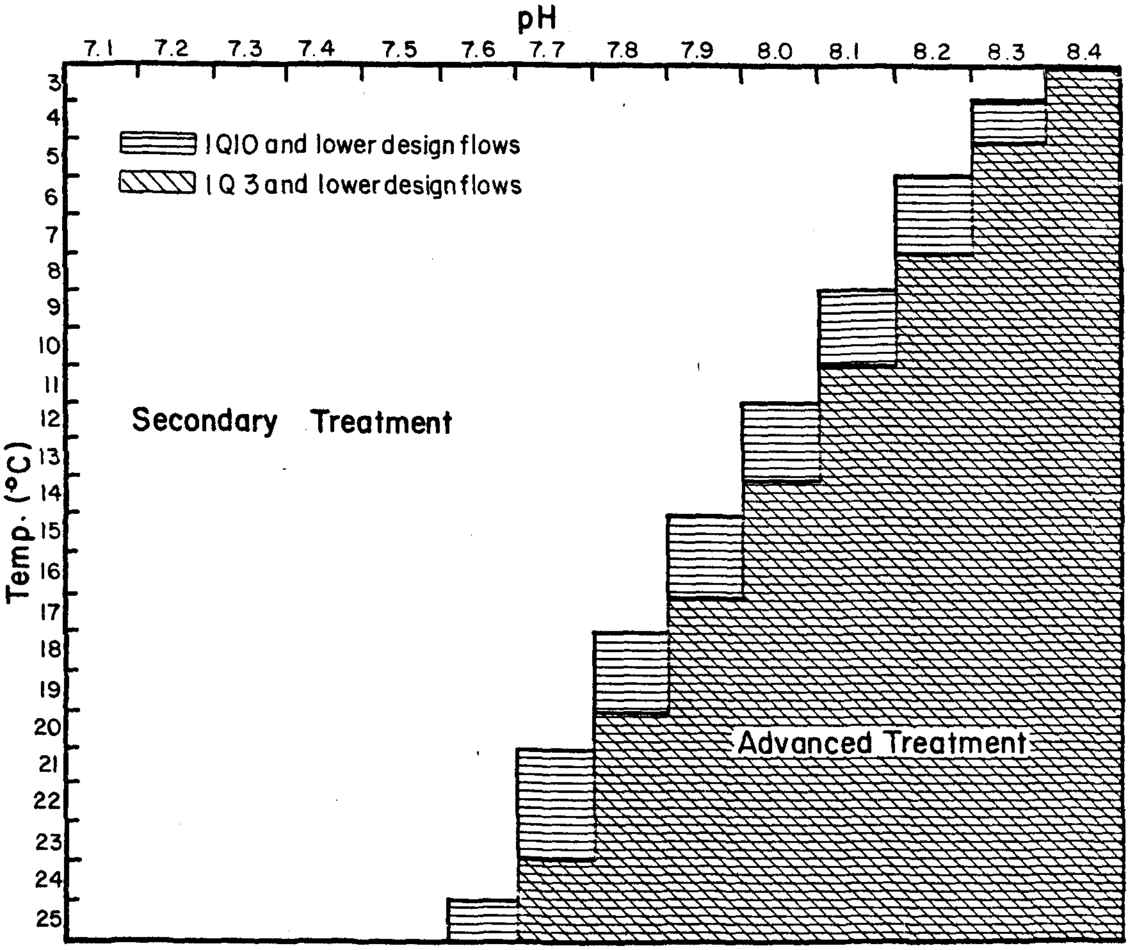

Figure B2.1 Ammonia treatment requirements for Englewood based on acute design flows and an acute instream ammonia standard of 0.20 mg/l-N.

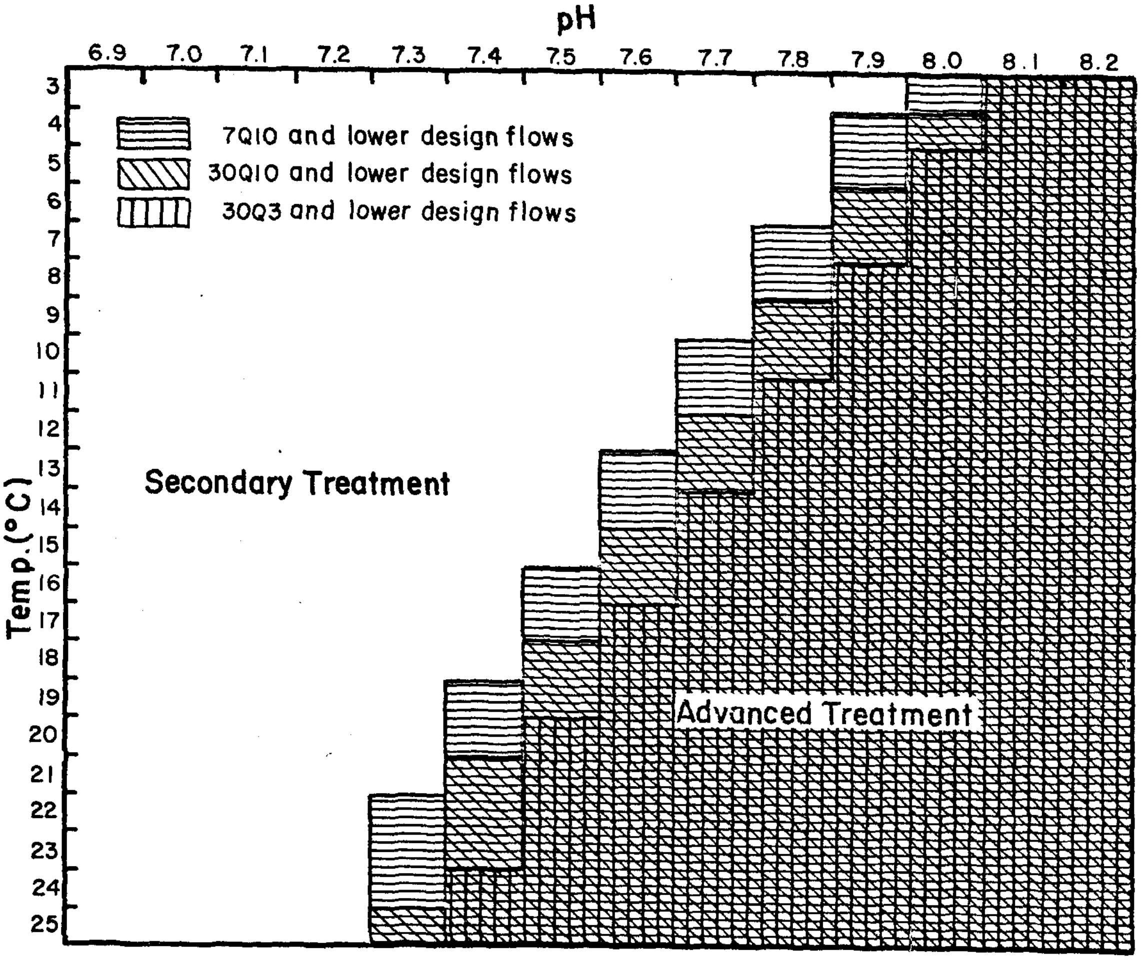

Figure B2.2 Ammonia treatment requirements for the City of Boulder based on acute design flows and an instream ammonia standard of 0.20 mg/l-N.

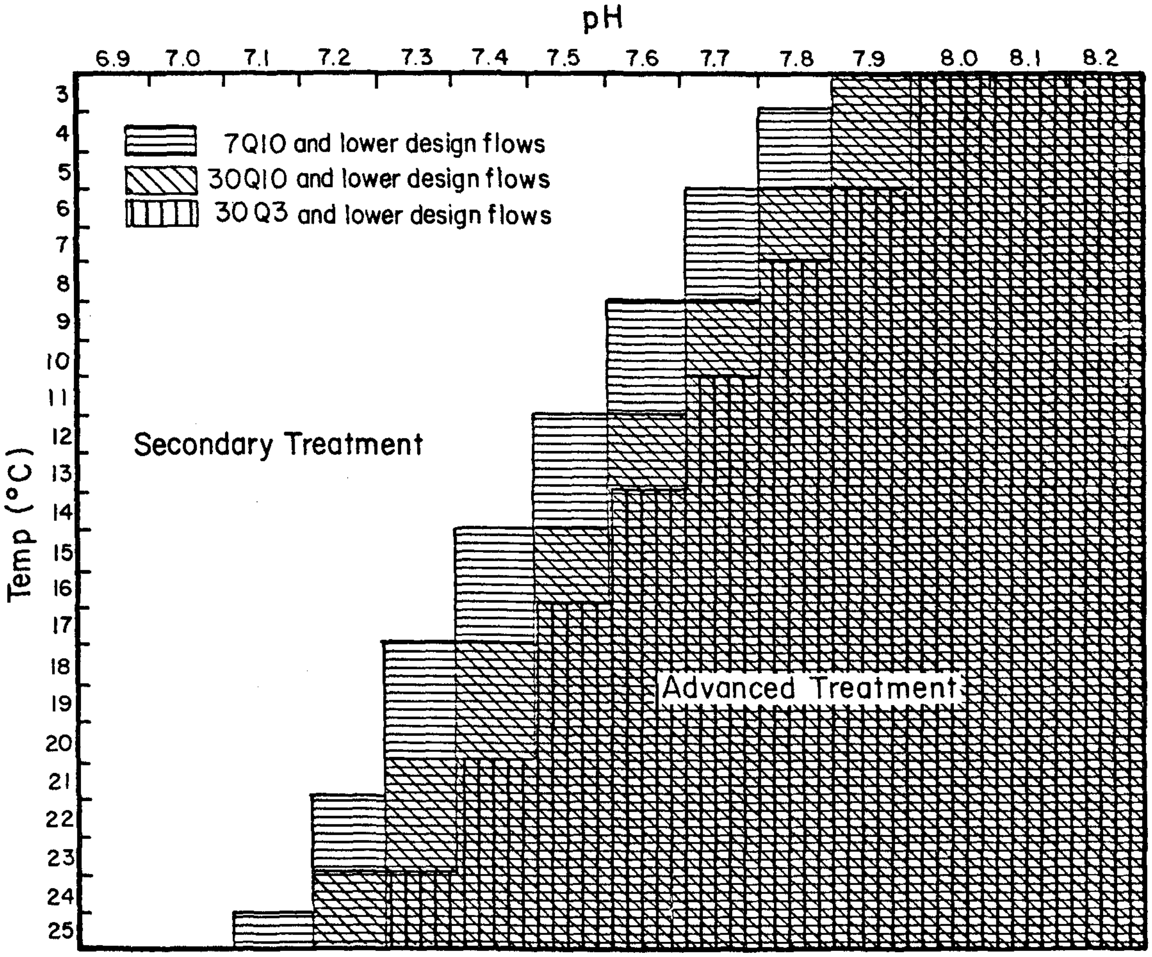

Figure B2.3 Ammonia treatment requirements for the City of Longmont based on acute design flows and an instream ammonia standard of 0.20 mg/l-N.

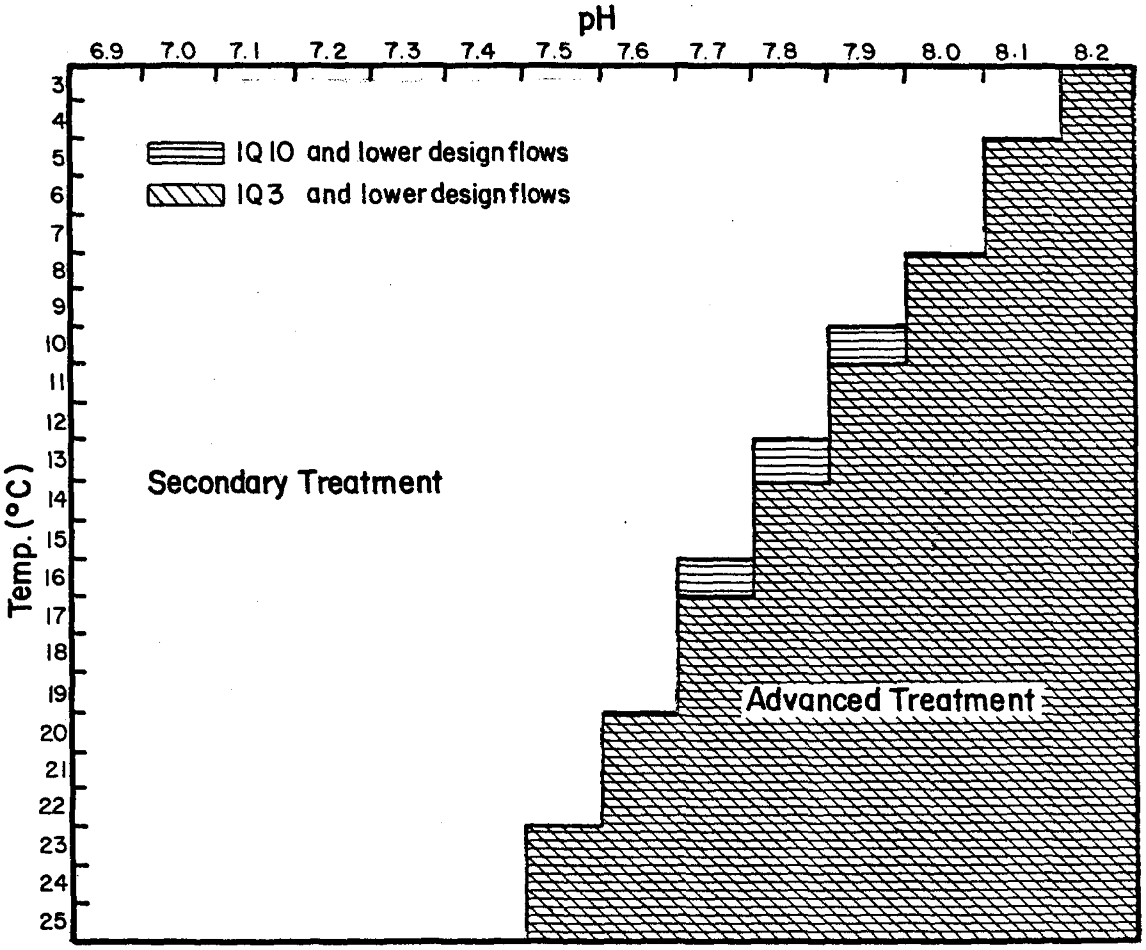

Figure B2.4 Ammonia treatment requirements for the City of Fort Collins based on acute design flows and an instream ammonia standard of 0.20 mg/l-N.

Table B5.1. Estimates of downstream unionized ammonia concentrations for Englewood.

1Q10 = 24 cfs
Ammonia = 18 mg/l in effluent; 9.6 mg/l in river after mix
Q_{plant} = 28 cfs

Month	Number of Excursions	T_s	T_p	$\bar{T}$	pH_s	pH_p	$\overline{pH}$	%	C
June	2	14.8	19	17.06	7.8	6.9	7.12	0.480	0.047
July	5	18.5	20	19.31	7.8	7.0	7.21	0.713	0.069
Sept.	25	15.5	21	18.46	7.9	7.0	7.22	0.683	0.066
Oct.	16	10.4	19	15.03	7.9	7.0	7.22	0.531	0.051

Notation:

T_s, T_p = temperature of stream and plant, respectively (°C)

$\bar{T}$ = flow weighted average (°C)

pH_s, pH_p = pH of stream and plant, respectively

$\overline{pH}$ = flow weighted average of using molar concentration of hydrogen ions

% = percent of unionized ammonia as function of temperature and pH

C = calculated downstream unionized ammonia concentration

Table B5.2. Estimates of downstream unionized ammonia concentrations for Englewood.

7Q10 = 28 cfs
Ammonia = 18 mg/l in effluent; 9.0 mg/l in river after mix
Q_{plant} = 28 cfs

Month	Number of Excursions	T_s	T_p	$\bar{T}$	pH_s	pH_p	$\overline{pH}$	%	C
July	9	18.5	20	19.25	7.8	7.0	7.24	0.772	0.069
Aug.	1	19.2	21	20.10	7.9	7.0	7.25	0.818	0.074
Sept.	27	15.5	21	18.25	7.9	7.0	7.25	0.714	0.064
Oct.	18	10.4	19	14.7	7.9	7.0	7.25	0.553	0.049

Notation:

T_s, T_p = temperature of stream and plant, respectively (°C)

$\bar{T}$ = flow weighted average (°C)

pH_s, pH_p = pH of stream and plant, respectively

$\overline{pH}$ = flow weighted average of using molar concentration of hydrogen ions

% = percent of unionized ammonia as function of temperature and pH

C = calculated downstream unionized ammonia concentration

Table B5.3. Estimates of downstream unionized ammonia concentrations for Englewood.

30Q10 = 36 cfs
Ammonia = 18 mg/l in effluent; 7.87 mg/l in river after mix
Q_{plant} = 28 cfs

Month	Number of Excursions	T_s	T_p	$\bar{T}$	pH_s	pH_p	$\overline{pH}$	%	C
Jan.	8	1.5	14	6.97	7.8	6.9	7.19	0.304	0.024
April	8	8.0	16	11.5	8.0	7.0	7.31	0.433	0.034
June	4	14.8	19	16.64	7.8	6.9	7.19	0.559	0.044
July	19	18.5	20	19.16	7.8	7.0	7.28	0.815	0.064
Aug.	4	19.2	21	19.99	7.9	7.0	7.29	0.818	0.064
Sept.	45	15.5	21	17.91	7.9	7.0	7.29	0.691	0.054
Oct.	39	10.4	19	14.16	7.9	7.0	7.29	0.574	0.045

Notation:

T_s, T_p = temperature of stream and plant, respectively (°C)

$\bar{T}$ = flow weighted average (°C)

pH_s, pH_p = pH of stream and plant, respectively

$\overline{pH}$ = flow weighted average of using molar concentration of hydrogen ions

% = percent of unionized ammonia as function of temperature and pH

C = calculated downstream unionized ammonia concentration

Table B5.4. Estimates of downstream unionized ammonia concentrations for Englewood.

30Q3 = 53 cfs
Ammonia = 18 mg/l in effluent; 6.22 in river after mix
Q_{plant} = 28 cfs

Month	Number of Excursions	T_s	T_p	$\bar{T}$	pH_s	pH_p	$\overline{pH}$	%	C
Jan.	138	1.5	14	5.82	7.8	6.9	7.27	0.288	0.018
Feb.	104	3.4	13	6.72	7.8	6.9	7.27	0.309	0.019
Mar.	91	5.4	14	8.37	7.9	6.9	7.29	0.368	0.023
April	63	8.0	16	10.77	8.0	7.0	7.39	0.528	0.033
May	11	11.2	17	13.20	7.8	6.9	7.27	0.514	0.032
June	18	14.8	19	16.25	7.8	6.9	7.27	0.644	0.040
July	39	18.5	20	19.02	7.8	7.0	7.35	0.915	0.0057
Aug.	21	19.2	21	19.82	7.9	7.0	7.37	1.00	0.062
Sept.	171	15.5	21	17.40	7.9	7.0	7.37	0.844	0.052
Oct.	137	10.4	19	13.37	7.9	7.0	7.37	0.667	0.041
Nov.	60	4.7	17	8.95	7.8	7.0	7.35	0.445	0.028
Dec.	83	1.4	15	6.10	7.8	7.0	7.35	0.339	0.021

Notation:

T_s, T_p = temperature of stream and plant, respectively (°C)

$\bar{T}$ = flow weighted average (°C)

pH_s, pH_p = pH of stream and plant, respectively

$\overline{pH}$ = flow weighted average of using molar concentration of hydrogen ions

% = percent of unionized ammonia as function of temperature and pH

C = calculated downstream unionized ammonia concentration

APPENDIX B

EPA Ammonia Program Equations (Willingham, 1976)

For practical purposes, the method for calculating the percentages of un-ionized ammonia as suggested by the European Inland Fisheries Advisory Commission (1970) will be used as shown in Table II.

Table II. Method for calculating the percentages of un-ionized ammonia present in ammonia-water solutions.

In ammonia-water solutions, un-ionized ammonia exists in equilibrium with the ammonium ion and hydroxide ion. Butler (1964) shows the equation expressing this equilibrium as:

$$NH_{3(g)} + nH_2O(1) \qquad NH_3{*}nH_2O_{(aq)} \qquad NH_4^+ + OH^- + (n-1)\ H_2O(1)$$

Derivation formula: $\dfrac{(NH_4^+)\ (OH^-)}{(NH_3{*}H_2O)} = Kb$

Temperature °C	$pk_{w(a)}$	$pk_{b(b)}$	$pk_{a(c)}$
0	14.944	4.862	10.082
5	14.734	4.830	9.904
10	14.535	4.804	9.731
15	14.346	4.782	9.564
20	14.167	4.767	9.400
25	13.997	4.751	9.246
30	13.833	4.740	9.093
35	13.680	4.733	8.947

(a) pk_w values from the Handbook of Chemistry and Physics 50th edition, 1969, page D-120. The Chemical Rubber Company.

(b) R. G. Bates and G. D. Pinching, J. Am. Chem. Soc., 1950, 72:1393.

(c) Bates and Pinching (1949) critically evaluated the constants for the dissociation of the ammonium ion at five-degree intervals from 0 to 50 C. In determining the constants at intermediate temperatures, the temperature dependence of the pK values must be established. In a recent excellent analysis of the literature data on the ammonia-water equilibrium system, Thurston, Russo, and Emerson (1974) devised such a calculated coefficient utilizing computer techniques which statistically represent a completely adequate fit to the Bates and Pinching data. Thurston, Russo and Emerson have suggested the following equation to calculate pK_a at all temperatures, in ammonia-water solutions of zero salinity:

$$pK_a = 0.09018 + 2729.92/T$$
$$\text{Where } T = {}^{\circ}C + 273.2$$

This equation has been used in this document.

(1) $\dfrac{(NH_4^+)\ (OH^-)}{(NH_3 * H_2O)} = Kb$, where Kb is the dissociation constant for ammonia

(2) $\dfrac{(NH_4^+)}{(NH_3 * H_2O)} = \dfrac{Kb}{(OH^-)}$

(3) $(NH_4^+) = \dfrac{Kb}{(OH^-)} (NH_3 * H_2))$

(4) $(NH_4^+) + (NH_3 * H_2O) = \text{ammonia}$

(5) Substituting the value for (NH_4^+) from equation (3) into equation (4),

$$\frac{Kb}{(OH^-)} (NH_3 * H_2O) + (NH_3 * H_2O) = \text{ammonia}$$

(6) By factoring out $(NH_3 * H_2O)$

$$NH_3 * H_2O \left(1 + \frac{Kb}{(OH^-)}\right) = \text{ammonia}$$

(7) $\dfrac{NH_3 * H_2O \times 100}{\text{ammonia}} = \dfrac{100}{1 + \dfrac{Kb}{(OH^-)}} = \text{Percent un-ionized ammonia}$

(a) $K_w = K_a K_b$

(b) $K_b = \dfrac{K_w}{K_a}$

(c) $\dfrac{Kb}{(OH^-)} = \dfrac{Kw}{K_a (OH^-)} = \dfrac{(OH^-)\ (H^+)}{K_a (OH^-)} = \dfrac{(H^+)}{K_a} = \text{antilog } (pK_a - pH)$

(8) $\text{Percent un-ionized ammonia} = \dfrac{100}{1 + \text{antilog}\ (pK_a - pH)}$

Given a maximum permissible in-stream concentration of un-ionized ammonia of 0.02 mg/l NH_3-N,

(9) Then, $\dfrac{0.02\ \text{mg/l}\ NH_3\text{-N} \times 100}{\text{percent un-ionized ammonia}} = \text{ammonia - N}$

APPENDIX C

Glossary of Terms

acute flow - the design flow associated with the acute water quality maximum concentration protecting aquatic life from unacceptable short-term effects. Duration of flow is one hour, but for practical purposes, the flow duration is one day.

acute-to-chronic ratio - ratio determined in lab to estimate the ccc.

biologically-based method - an empirical approach recommended by EPA determining the design flow based upon the actual number of excursions in the historical data.

chi-square, χ^2 - a statistic which is used to estimate the goodness of fit of a set of data to a distribution.

chronic flow - the design flow associated with the chronic water quality concentration to protect ecosystems from unacceptable effects due to long-term exposure - duration of the flow is 4 days.

climatic year - the year for estimating low flow statistics, April 1-March 31, as opposed to the water year, October 1-September 31.

C_v - coefficient of variation which is the standard deviation divided by the mean.

confidence interval - an interval which brackets a statistic at a given level of significance.

correlation coefficient - a measure of a variables dependence on another variable. It varies from minus one to one.

CCC - criterion continuous concentration is the chronic concentration which is equal to the FAV divided by the final acute to chronic ratio.

CMC - criterion maximum concentration, acute concentration used by EPA, which is equal to one half of the FAV.

CSU - Colorado State University, Fort Collins, Colorado 80523.

Cyber 205 - class of supercomputer used at Colorado State University.

DFLOW - computer program of the water quality model used by the EPA estimating downstream concentrations of unionized ammonia based upon temperature, pH, upstream conditions and discharge conditions.

design flow - the flow which is available for dilution when estimating the available effluent loads.

DNR - Department of Natural Resources.

effluent river - a river which is the effluent of the groundwater, i.e. the groundwater contributing to the river.

EPA - Environmental Protection Agency.

excursion - a flow below a given threshold level which can have various durations.

FAV - final acute value, based upon toxicity test results 48- or 96-hour LC50.

F-test - a statistical test which is used in the analysis of variance.

frequency statistic - any statistic based upon a frequency distribution, i.e. 7Q10, 1Q3, etc.

influent river - a river that is influent to the groundwater, i.e. contributing to the groundwater.

kurtosis - the fourth moment of a population, a measure of the roundness of the distribution.

lag-one autocorrelation - a measure of correlation between time series data separated by one time unit.

mean - the first moment of a distribution and is estimated from the data using the average.

median - the middle value which has a 50 percent chance of being exceeded.

moving average - an average of a sequence in a time series.

NPDES - National Pollution Discharge Elimination System.

overlapping procedure - using data from previous month and subsequent month in the determination of moving averages in a month. For example, when calculating the seven-day moving averages for the month of July the last 3 days in June and the first 3 days in August are used.

partial-duration series - a time series used in estimating flow statistics which are determined by estimating a threshold value and using all data (below for low flow analysis), unlike an annual series having only one flow per year; partial series will have more than one.

pp - plotting position which is an estimate of the probability of non-exceedence (in low flow analysis).

r^2 - coefficient of variation or determination, the correlation coefficient squared. A measure of how much is known about process, varies from zero to one.

recurrence interval - the reciprocal of the probability of occurrence and is the average time interval between the occurrence of the events.

robust - the measure of the appropriateness of the assumption of normality. A robust hypothesis test does not depend entirely on a normality assumption of the population.

run length - the length of time that a process is occurring.