Introduction

The major streams in Nevada have had TMDLs[1] (Total Maximum Daily Loads) established for several years. However for some of these streams, the TMDLs are expressed as an average daily load based upon average long term flow conditions. These TMDLs have been dubbed as "bare bones" TMDLs due to the simplicity of the calculation and their lack of usefulness. While these TMDLs seem to satisfy the requirements of the Clean Water Act, they have contributed little to any watershed/waterbody assessment and restoration plans. These types of TMDLs do little to characterize the problems the TMDLs are intended to address. Without adequate characterizations, appropriate solutions cannot be identified and implemented.

For TMDLs to be more beneficial in the assessment and implementation process, TMDLs should reflect adequate water quality across flow conditions rather than at a single flow event such as average daily flow. Many states have begun to use load duration curves as a more robust method for setting TMDL targets. It is also a useful tool for better characterizing the pollutant problems over the entire flow regime. This paper discusses the steps taken to develop load duration curves and how they can be used in the assessment and TMDL process.

Steps in Developing a Load Duration Curve

A duration curve is a graph representing the percentage of time during which the value of a given parameter (e.g. flow, load) is equaled or exceeded. Such a graph can be easily generated using a spreadsheet computer program. The following presents the steps involved in developing a load duration curve.

Step 1. Develop Flow Duration Curve: Using available daily streamflow data, a flow duration curve is developed for the site in question. Data for the curve is generated by: 1) ranking the daily flow data from highest to lowest; 2) calculating percent of days these flows were exceeded (= rank ÷ number of data points). Table 1 and Figure 1 present a portion of the ranked data and resulting flow duration curve for USGS Gaging Station 10311000 – Carson River near Carson City, Nevada for a 20-year period.

Table 1. Flow Duration Curve Data – Sta. 10311000 Carson River near Carson City, NV (1982-2001)

Daily Streamflow (cfs)	Rank	Percent of Days Flow Exceeded
26,100	1	.01%
14,000	2	.03%
11,500	3	.04%
11,200	4	.05%
10,100	5	.07%
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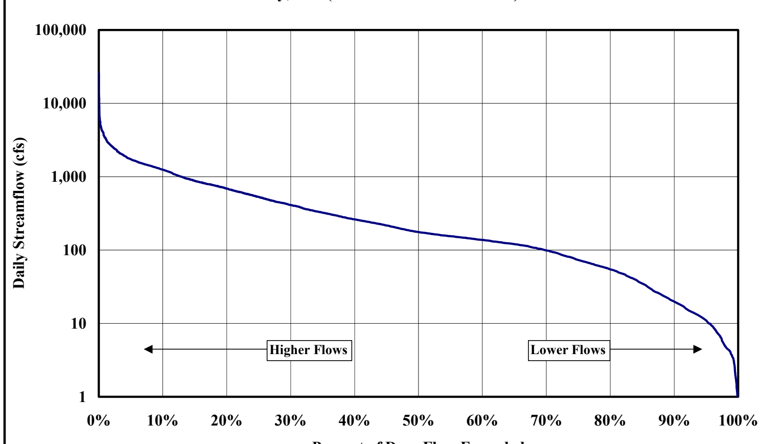
0.32	7301	99.95%
0.27	7302	99.96%
0.26	7303	99.97%
0.19	7304	99.99%
0.01	7305	100.00%

Figure 1. Flow Duration Curve - Sta. 10311000 Carson River near Carson City, NV (Water Years 1982-2001)



[1] Total Maximum Daily Load is the pollutant load that a waterbody can assimilate without violating the water quality standards for that pollutant.

Step 2. Develop Load Duration Curve: The load duration curve is developed by multiplying the streamflows in Table 1 by the water quality standard for the parameters under examination and by a conversion factor (see Equation 1). For this example, the total phosphorus standard of 0.1 mg/l is used. The calculation results are partially shown in Table 2. To apply a 10% margin of safety (MOS), the results of Equation 1 are divided by 1.1. In this case, a 10% MOS was selected to account for uncertainties in the gaged flow data.

Load (pounds per day) = streamflow (cfs) x 0.1 mg/l x 5.396 *[Eq. 1]*

Table 2. Load Duration Curve Data – Sta. 10311000 Carson River near Carson City, NV (1982-2001)

Daily Streamflow (cfs)	Rank	Percent of Days Flow Exceeded	Allowable Load at the Standard (#/day)	Allowable Load with 10 % Margin of Safety (#/day)
26,100	1	.01%	14,084	
14,000	2	.03%	7,554	
11,500	3	.04%	6,205	
11,200	4	.05%	6,044	
10,100	5	.07%	5,450	
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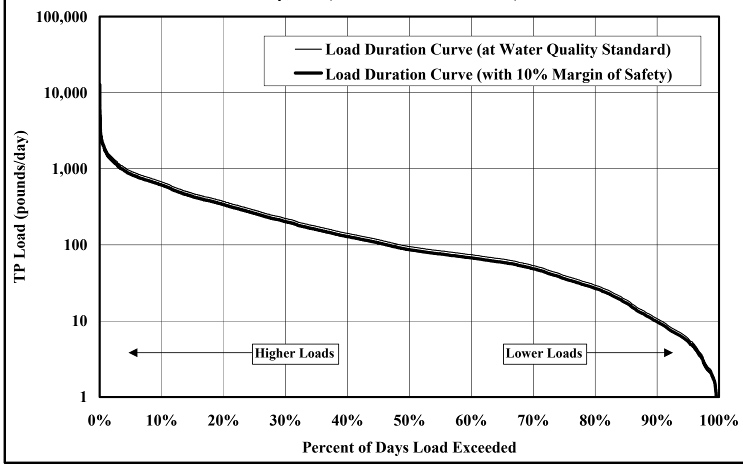
0.32	7301	99.95%	0.17	
0.27	7302	99.96%	0.15	
0.26	7303	99.97%	0.14	
0.19	7304	99.99%	0.10	
0.01	7305	100.00%	0.01	

Figure 2. TP Load Duration Curve - Sta. 10311000 Carson River near Carson City, NV (Water Years 1982-2001)

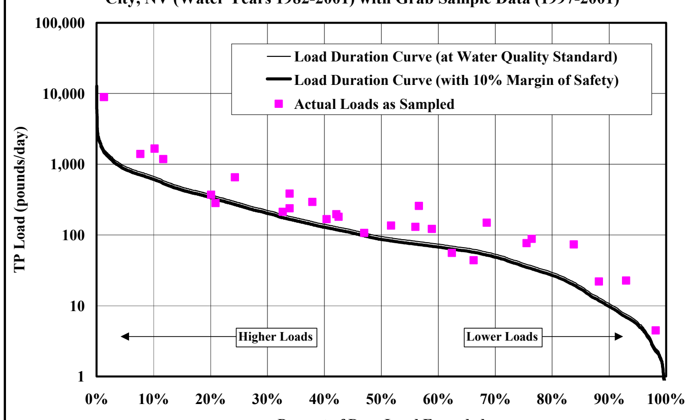


Step 3. Plot Water Quality Sample Data on Load Duration Curve: In order to compare water quality sample data to the load duration curve, the first task is to calculate daily loads for each sample using Equation 1 along with the pollutant concentration and streamflow for the particular day (Table 3). Next, the flow values for each day are compared to the flow duration curve data in order to determine the value for "Percent of Days Flow Exceeded" which is equivalent to "Percent of Days Load Exceeded". These load and percent data points are then plotted on the load duration curve (Figure 3). Points above the curve represent exceedances of the water quality standards and the associated allowable loadings.

Table 3. Total Phosphorus Data for Sta. 10311000 Carson River near Carson City, NV (1997-2001)

Date	(mg/l)	Actual Load (lbs/day)	(cfs)	Percent of Days Flow Exceeded
12-Mar-97	0.08	282.32	654	20.9%
28-May-97	0.20	1,176.33	1090	11.7%
22-Jul-97	0.26	148.71	106	68.5%
16-Sep-97	0.20	76.62	71	75.5%
12-Nov-97	0.15	135.98	168	51.7%
. . .	. . .	. . .	. . .	. . .
9-Jan-01	0.07	43.82	116	66.2%
21-Mar-01	0.21	383.01	338	33.9%
29-May-01	0.13	237.10	338	33.9%
17-Jul-01	0.30	22.66	14	93.0%
25-Sep-01	0.18	4.47	4.6	98.2%

Figure 3. TP Load Duration Curve - Sta. 10311000 Carson River near Carson City, NV (Water Years 1982-2001) with Grab Sample Data (1997-2001)



Use of Load Duration Curves in Assessments and TMDLs

The load duration curve as shown in Figure 3 has a number of uses and benefits:

- The load duration curve approach is useful for characterizing the problem and providing a visual display for people to better understand the problem and the TMDL targets. With the load duration curves, the frequency and magnitude of the water quality standards and allowable loads are easily presented. The magnitude of loading reduction can be better understood.

- Load duration curves can be used to characterize flow conditions under which standard exceedances are occurring. In general, exceedances that occur in the 0 to 10% area of the curve may be considered to represent unique high flow problems that may exceed feasible management remedies. Exceedances in the 99 to 100% reflect extreme drought conditions.

- Different loading mechanisms can dominate at different flow regimes. The load duration curve can be used to begin differentiating between nonpoint source and point source problems. In general, exceedances of the load duration curve during the higher flows can be indicative of nonpoint source problems. Exceedances during the lower flows can be indicative of point source problems. However, each waterbody must be considered on a case by case basis.

- Load duration curves can show seasonal water quality effects. Data points that cluster within a narrow range of the percent of load exceeded can be associated with the season when that range of flows typically occur.

- Water quality conditions between multiple reaches and watersheds can be examined through the comparison of load duration curves at different sites.

- Using the load duration as a TMDL target, TMDLs can be developed which set load limitations over the entire flow range, not just for an annual average. With this type of target, the goal of the TMDL may be to reduce the number of samples exceeding the load duration curve (or TMDL target) to less than 10% (in accordance with Nevada's 303(d) List methodology for non-impairment) for the period of concern. For many waterbodies in Nevada, there is inadequate data to calculate historic loads making it extremely difficult to accurately quantify load reduction requirements. The load duration curve approach provides another means to develop TMDLs for these systems.

- In many instances, it is desirable to have a monitoring regime that results in water quality data representing conditions for a wide range of flows. By plotting the load duration curve and historic water quality data, one can quickly determine how well (or poorly) the samples are distributed over the range of flows.

Shortcomings of the Load Duration Curve Method

It must be recognized that the load duration curve approach has some shortcomings. In using the load duration methodology, it is assumed that the particular water quality standard is appropriate and protective of the beneficial use(s) over the entire flow regime. This may or may not be the case depending upon the pollutant. For the health of a system to be adequately assessed, TMDLs ultimately need to address more than water chemistry. The physical and biological conditions of the waterbody are extremely important in supporting the array of beneficial uses set for the waterbody. Use of the load duration curve provides only one part of a complex picture.

Not only are there uncertainties with the water quality standards and the associated load duration curves, but one must critically consider the use of the "less than 10%" exceedance threshold as the TMDL goal. While this value is commonly used by many states in their assessments, actual allowable exceedance frequency could be more or need to be less than 10% for the support of the beneficial uses, again depending upon the particular waterbody and pollutant.