APPENDIX E
GENERAL METHODS FOR ESTIMATING FLOW AT TMDL WQM STATIONS

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Flow duration curve analysis looks at the cumulative frequency of historic flow data over a specified period (USEPA 2007). Because stream flow conditions on any given day can be highly variable, depending on watershed characteristics and weather patterns, flow duration curves are a useful tool for characterizing the percentage of days in a year when given flows occur (USEPA 2007). To support the development of bacteria TMDLs, flow duration curves can be developed using existing USGS measured flow where the data exist at the same location as the WQM station, or by estimating flow for WQM stations with no corresponding flow record. Flow data are derived and synthesized to support preparation of flow duration curves and load duration curves for each WQM station in this report in the following priority.

USGS Gage Coincides with WQM Station

In cases where a USGS flow gage coincides with, or occurs within one-half mile upstream or downstream of the WQM station the following protocols will be employed:

If simultaneous daily flow data matching the water quality sample date are available, these flow measurements will be used to prepare flow exceedance percentiles.

If flow measurements at the coincident gage are missing for some dates on which water quality samples were collected, the gaps in the flow record will be filled, or the record will be extended, by estimating flow based on measured streamflows at a nearby gages. First, the most appropriate nearby stream gages are identified as those within a 150 km radius that have at least 300 coincident daily flow measurements. For all identified gages, four regression equations are calculated on the coincident data. The calculated regressions include a linear regression, log-linear regression, logarithmic regression and a power curve regression. For each regression, the root mean square error (RMSE) is calculated and the equation with the best fit or lowest RMSE is chosen to represent that gage. The gages are ranked in order of best fit or increasing RMSE. As many data points requiring filling as possible are filled with the best fit gage (lowest RMSE). If dates remain to be filled, the process is repeated in an iterative fashion with the second best fit gage and so forth until all dates requiring filling have been filled.

No USGS Gage Coincides with WQM Station

Where no coincident flow data are available for a WQM station, but flow gage(s) are present upstream and/or downstream, flows will be estimated for the WQM station from an upstream or downstream gage using a watershed area ratio method that includes a modification utilizing the NRCS Curve number (CN) to account for differences in watersheds (Wurbs & Sisson, 1999; Wurbs 2006). In coastal watersheds, where the choice of using an upstream or downstream station may be severely limited, it may be necessary to use a gage station from an adjacent watershed that has similar characteristics. These recent studies have demonstrated that, while flow predictions for a specific time with any flow distribution method are not highly accurate, RMSE, means and others flow characteristics can be estimated with an acceptable degree of accuracy. Since many of the flow frequencies important to a load duration curve involve the low end of the frequency range and the NRCS Curve method involves inherent limitations as flows approach the initial abstraction limit, another modification was applied to this method.

The Furness method (Furness 1959) employed by the USGS in Kansas (Studley 2000) estimates flow duration curves by estimating several descriptive statistics that describe the curve. The adaptation was included to utilize the existing period of record to calculate the flow frequency curve for an individual USGS gage, which completely describes the shape of the curve. The mean flow is then projected to the ungaged location utilizing the modified NRCS Curve method, which operates best around the mean of a distribution. Individual flow measurements and flow frequencies can then be projected to the ungaged location by normalizing them to the percent of the mean flow and multiplying the result by the newly projected mean flow for the ungaged location.

Drainage subbasins will first be delineated for all impaired 303(d)-listed WQM stations, along with all USGS flow stations located in the 8-digit HUCs with impaired streams. All the USGS gage stations will be identified that have a continuous period of record upstream and downstream of the subwatersheds with 303(d) listed WQM stations.

Watershed delineations are performed using ESRI Arc Hydro with a 30 m resolution National Elevation Dataset (NED) digital elevation model, and National Hydrography Dataset (NHD) streams. The area of each watershed will be calculated following watershed delineation.

The watershed average curve number is calculated from soil properties and land cover as described in the U.S. Department of Agriculture (USDA) Publication TR-55: Urban Hydrology for Small Watersheds. The soil hydrologic group is extracted from NRCS STATSGO soil data, and land use category from the NOAA Coastal Change Analysis Program (C-CAP). Based on land use and the hydrologic soil group, SCS curve numbers are estimated at the 30-meter resolution of the C-CAP grid as shown in Table E-1.

The average curve number is then calculated from all the grid cells within the delineated watershed.

The average rainfall is calculated for each watershed from gridded average annual precipitation datasets for the period 1971-2000 (Spatial Climate Analysis Service, Oregon State University, http://www.ocs.oregonstate.edu/prism/, created 20 Feb 2004).

Table E-1   Runoff Curve Numbers for Various Land Use Categories and Hydrologic Soil Groups

C-CAP Value	C-CAP Class	Group A	Group B	Group C	Group D
2	High-Intensity Developed	89	92	94	95
3	Medium-Intensity Developed	77	85	90	92
4	Low-Intensity Developed	61	75	83	87
5	Open-Space Developed	39	61	74	80
6	Cultivated Land	67	78	85	89
7	Pasture/Hay	35	56	70	77
8	Grassland/Herbaceous	39	61	74	80
9	Deciduous Forest	30	55	70	77
10	Evergreen Forest	30	55	70	77
11	Mixed Forest	30	55	70	77
12	Scrub/Shrub	30	48	65	73
13	Palustrine Forested Wetland	0	0	0	0
14	Palustrine Scrub/Shrub Wetland	0	0	0	0
15	Palustrine Emergent Wetland	0	0	0	0
16	Estuarine Forested Wetland	0	0	0	0
17	Estuarine Scrub/Shrub Wetland	0	0	0	0
18	Estuarine Emergent Wetland	0	0	0	0
19	Unconsolidated Shore	0	0	0	0
20	Bare Land	77	86	91	94
21	Water	0	0	0	0
22	Palustrine Aquatic Bed	0	0	0	0
23	Estuarine Aquatic Bed	0	0	0	0

The mean flow at the ungaged site is calculated from the gaged site utilizing the modified NRCS Curve Number method (Wurbs & Sisson, 1999). The NRCS runoff curve number equation is:

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \qquad (1)$$

where:

Q = runoff (inches)

P = rainfall (inches)

S = potential maximum retention after runoff begins (inches)

I_a = initial abstraction (inches)

If $P < 0.2$, $Q = 0$. Initial abstraction has been found to be empirically related to S by the equation

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$$I_a = 0.2*S \qquad (2)$$

Thus, the runoff curve number equation can be rewritten:

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \qquad (3)$$

S is related to the curve number (CN) by:

$$S = \frac{1000}{CN} - 10 \qquad (4)$$

First, S is calculated from the average curve number for the gaged watershed. Next, the historic mean flow at the gage is converted to depth basis (as used in equations 1 and 3) by dividing by its drainage area, then converted to inches. Equation 3 is then solved for daily precipitation depth of the gaged site, P_{gaged}. The daily precipitation depth for the ungaged site is then calculated as the precipitation depth of the gaged site multiplied by the ratio of the long-term average precipitation in the watersheds of the ungaged and gaged sites:

$$P_{ungaged} = P_{gaged}\left(\frac{M_{ungaged}}{M_{gaged}}\right) \qquad (5)$$

where M is the mean annual precipitation of the watershed in inches. The daily precipitation depth for the ungaged watershed, along with the average curve number of the ungaged watershed, are then used to calculate the depth equivalent daily flow Q of the ungaged site. Finally, the volumetric flow rate at the ungaged site is calculated by multiplying by the area of the watershed of the ungaged site and converting the value to cubic feet.

If wastewater treatment facilities (WWTF) are located within the drainage area of the USGS gage, a base flow for the USGS gage should be calculated before projecting flow to an ungaged site. The base flow for the USGS gage is calculated by deducting the sum of the Average Monthly WWTF flow for all outfalls in the drainage area from the measured USGS flow record. The Average Monthly WWTF flows are applied for each day (1-31) of a given month.

$$Q_{baseflow} = Q_{USGSgage} - \sum_{\#wwtf}^{1} Q_{Avg.MonthlyWWTF}$$

If the base flow results in a negative value, that value is then set to zero.

After flow has been estimated for the ungaged site, average monthly flows from WWTFs that drain into the ungaged watershed are then added to the flow estimates.

In the rare case where no coincident flow data are available for a WQM station <u>and</u> no gages are present upstream or downstream, flows will be estimated for the WQM station from a gage on an adjacent watershed of similar size and properties, via the same procedure described above for upstream or downstream gages.

USEPA 2007. An Approach for Using Load Duration Curves in the Development of TMDLs. EPA 841-B-07-006 August 2007. http://www.epa.gov/owow/tmdl/techsupp.html

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Furness, L.W. 1959. Kansas streamflow characteristics- part 1, Flow duration: Kansas Water Resources Board Technical Report No. 1, 213 p.

Wurbs, R. A. 2006. Methods for Developing Naturalized Monthly Flows at Gaged and Ungaged Sites. Journal of Hydrologic Engineering, Vol. 11, No. 1, January 1, 2006.