Load Duration Curves

The TMDL for this Pesticide TMDL Report is expressed as a concentration. However, based on USEPA guidance, daily load expressions were developed to supplement the concentration-based TMDLs and allocations. Staff used a load duration curve analysis approach to estimate existing loads and assimilative capacity for organophophate pesticides (chlorpyrifos and diazinon) in the impaired stream segments in the lower Santa Maria Watershed.

1.1   Technical Approach and Methods

The load duration curve approach involves calculating the allowable loadings over the range of flow conditions expected to occur in the impaired stream by taking the following steps:

1. **Develop Flow Records for Key Water Quality Monitoring Stations**. A flow duration curve for the impaired segment (or subsegments) is developed using the available flow data. This is done by generating a flow frequency record consisting of ranking all of the observed flows from the least observed flow to the greatest observed flow and plotting those points. Direct flow measurements are not available for all of the water quality monitoring stations addressed in this FIB TMDL Report. This information, however, is important to understanding the relationship between water quality and stream flow. Therefore, to characterize flow in some cases, synthetic flow records were derived from commonly used flow estimation methods. Flow data to support development of flow duration curves were derived for key water quality monitoring sites from USGS daily flow records generally in the following priority; however, the final methodology is subject to best professional judgment:

> i)   In cases where a USGS flow gage coincides with, or occurs within one-half mile upstream or downstream of a water quality monitoring station and simultaneous daily flow data matching the water quality sample dates are available, these flow measurements will be used. If flow measurements at a USGS flow gage are missing for some dates on which water quality samples were collected, gaps in the flow record will be filled, or the record extended, by estimating flow based on measured stream flows at a nearby gage. First, the most appropriate nearby stream gage is identified. The station with the strongest flow relationship, as indicated by the highest correlation coefficient (R), or based on similar land use and hydrologic factors, is selected as the index gage. Data from the flow gage with the partial flow record is then compared to the flow record from the index gage using regression analysis. The regression equation is then used to estimate flow at the gage to be filled/extended from flows at the index station. Flows will not be estimated based on regressions with r-squared values less than 0.25, even if that is the best regression. This value was selected based on technical guidance for using regression analysis in estimating flows (USEPA 2007, and State of South Carolina DHEC, 2005). R-squared indicates the fraction of the variance in flow explained by the regression.

ii)   In cases where no USGS flow gage data is located within one-half mile upstream or downstream of a monitoring site, but instantaneous flow data is available at the monitoring site, mean daily discharge will be estimated by regressing the instantaneous flow measurements against mean daily values from the most appropriate nearby USGS flow gage. Flows will not be estimated based on regressions with r-squared values less than 0.25, even if that is the best regression.

iii)   In cases where no USGS flow gage data is available within one half mile upstream or downstream of a monitoring site, and no instantaneous flow data are available, but a USGS flow gage is located within the same stream reach (upstream or downstream) of the monitoring site, the Drainage Area Ratio method with be used to estimate mean daily flow at the ungaged site using the USGS flow data that is located along the same stream reach.

iv)   In drainages where there is no USGS flow gage or instantaneous flow data, mean daily flows will be estimated with the modified SWRCB proration drainage area method, using the mean daily flows from the most appropriate USGS flow gage record from a nearby drainage. The modified SWRCB proration drainage area method accounts for spatial variability in precipitation and runoff characteristics that might be expected between different drainages.

v)   For monitoring sites in drainages where there is no USGS flow gage or instantaneous flow data, but a synthetic flow record has been created for a monitoring site within the same stream reach upstream or downstream of the ungaged site, flow statistics will be transferred to the ungaged site from the site with the synthetic flow record by using the Drainage Area Ratio method.

2. Develop Flow Duration Curves. Flow duration curves are graphical representations of the historic flow regime of a stream at a given site over a period of time. Flow duration curves serve as the foundation for developing load duration curves. The flow duration curve represents the percent of flow values that exceed a given flow at a site.

To develop a flow duration curve flow values are first ranked from highest to lowest, then, for each observation, the percentage of observations exceeding that flow is calculated. For example the lowest measured flow occurs at an exceedance frequency of 100 percent, indicating that flow has equaled or exceeded this value 100 percent of the time, while the highest measured flow has an exceedance frequency of 0 percent and the median flow occurs at a flow exceedance frequency of 50 percent. Flow duration curves can be subjectively divided into several hydrologic flow regime classes. The flow duration curves were divided at 10 and 40 percent for the TMDL report..

3. Develop Load Duration Curves. Load duration curves are based on flow duration curves. Load duration curves display the allowable loading capacity (based on the relevant water quality criterion) across the continuum of flow percentiles and also displays historical pollutant load observations at the monitoring site. In lieu of flow, the y-axis is expressed in terms of a pesticide load (grams/day).

4. Plot Observed Loads. Each pollutant data point from observed data is converted to a daily load by multiplying the concentration by the corresponding average daily flow on the day the sample was taken. The load is then plotted on the load duration curve graph. Points plotting above the curve represent exceedances of the water quality objective (i.e., the allowable load, or total maximum daily load). Those plotting below the curve represent compliance with water quality objective and therefore represent compliance with the maximum daily loads.

5. Use Load Duration Curve to Develop Daily Load Expressions. The load duration curve itself can be established as the TMDL. The TMDL would be dynamic and based on flow. Essentially, the loading capacity is the load corresponding to the flow selected along the curve. Alternatively, a static TMDL can be established based on the area beneath the TMDL curve, representing the loading capacity of the stream. The difference between this area and the area representing current loading conditions is the load that must be reduced to meet water quality standards. As noted previously, staff are establishing concentration based TMDLs in accordance with 40 CFR 122.45(f) of the Clean Water Act. However, USEPA recommends supplementing a concentration-based TMDL with a daily load expression, as indicated below:

> "For TMDLs that are expressed as a concentration of a pollutant, a possible approach would be to use a table and/or graph to express the TMDL as daily loads for a range of possible daily stream flows. The in-stream water quality criterion multiplied by daily stream flow and the appropriate conversion factor would translate the applicable criterion into a daily target."*
>
> -- USEPA, 2007 "Options for Expressing Daily Loads in TMDLs",
> Office of Wetlands, Oceans and Watersheds, June 22, 2007.
> * emphasis added

1.2   Flow Duration Curves

Flow duration curves were developed for three sites in the Lower Santa Maria watershed: Green Valley Creek at Simas Road (312GVS), Orcutt Creek Upstream of the Santa Maria River (312ORC) and the Santa Maria River above the Estuary (312SMA).

As illustrated in Figures 1.1, 1.2 and 1.3 the flow duration curve increases along the x-axis with the greatest flows at the point along the y-axis. The flow duration curve is based on the daily average flow and each point on the x-axis represents a percent of time that a flow is met or exceeded. The zero value on the x-axis represents the highest observed flow and 100 represents the lowest observed flow that was exceeded of met 100 percent of the time. The y-axis represents flow in cubic feet per second (cfs) on a logarithmic scale. The flow duration interval was subjectively divided into three zones for the TMDL Report with one zone representing high flows (0-10%), another representing moderate flows (10-40%) and one representing low flows (40-100%).

The flow duration curves indicate that there is perennial flow in the streams. The curves have a moderate slope indicating fairly consistent year round flow with few peak flows.

The CMP conducted an irrigation season continuous flow study in 2008, which included the Green Valley Creek and Orcutt Creek. The CMP study found that *flows in Green Valley are very low, generally 0.4 to 1 cfs, but never 0 cfs* and that *flows in Orcutt-Solomon Creek are much higher than at other sites (median =6.9 cfs) and are never 0 cfs.* The CMP study also documented broad daily flow fluctuations that exceed fluctuations generally found in natural systems. These fluctuations likely correspond to the discharge of irrigation return water into the streams from adjacent lands. The fluctuations were greater in Green Valley than in Orcutt Creek, which has a greater base flow in the stream.
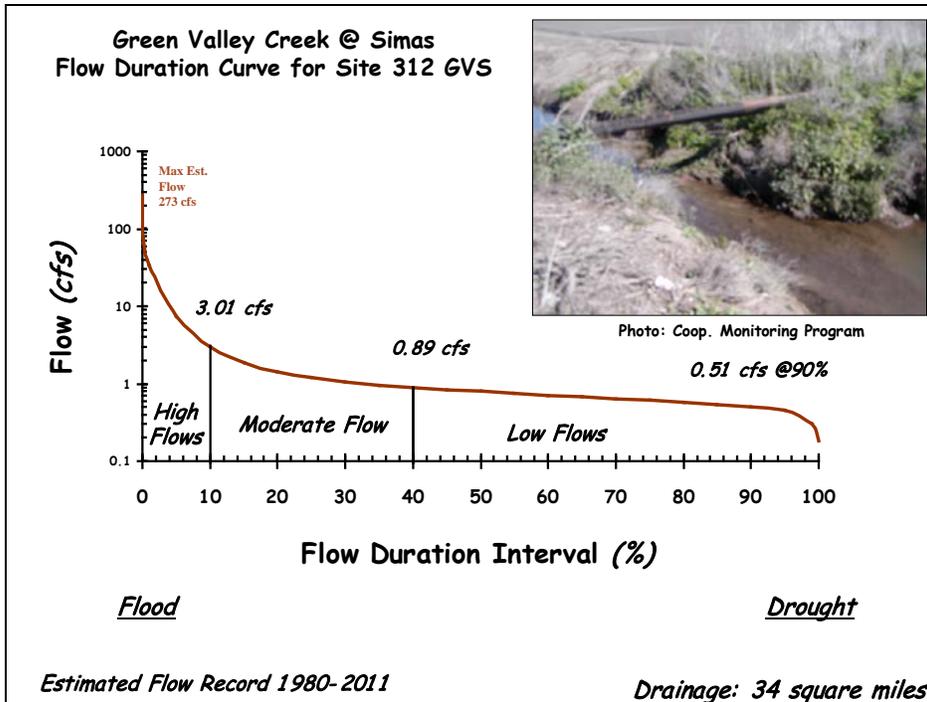
Figure 1-1 Flow Duration Curve Green Valley Creek
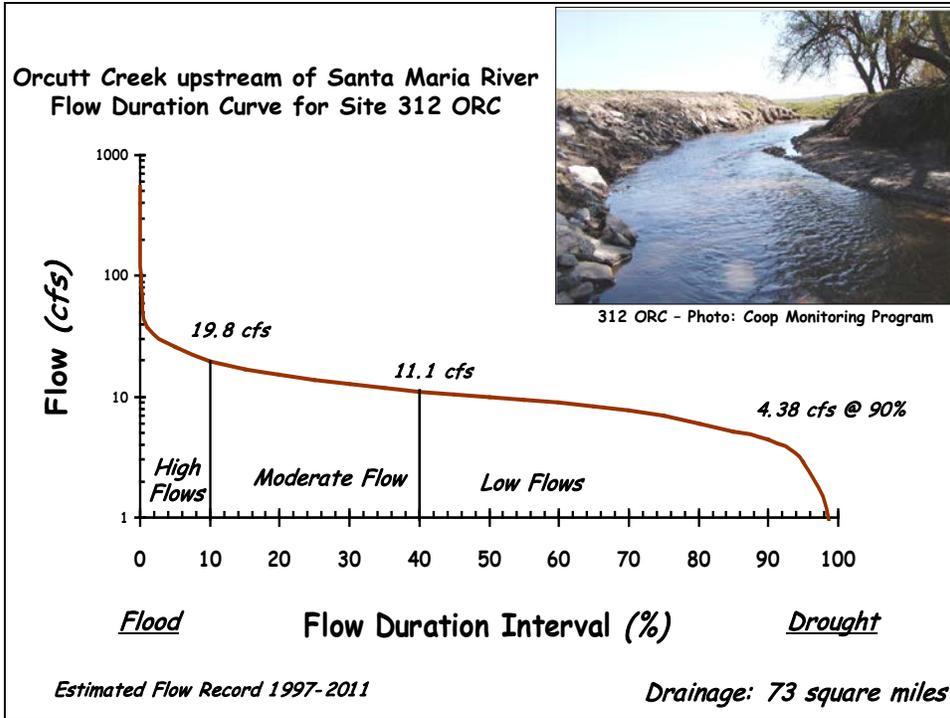
Figure 1-2 Flow Duration Curve Orcutt Creek upstream of the Santa Maria River (312ORC)
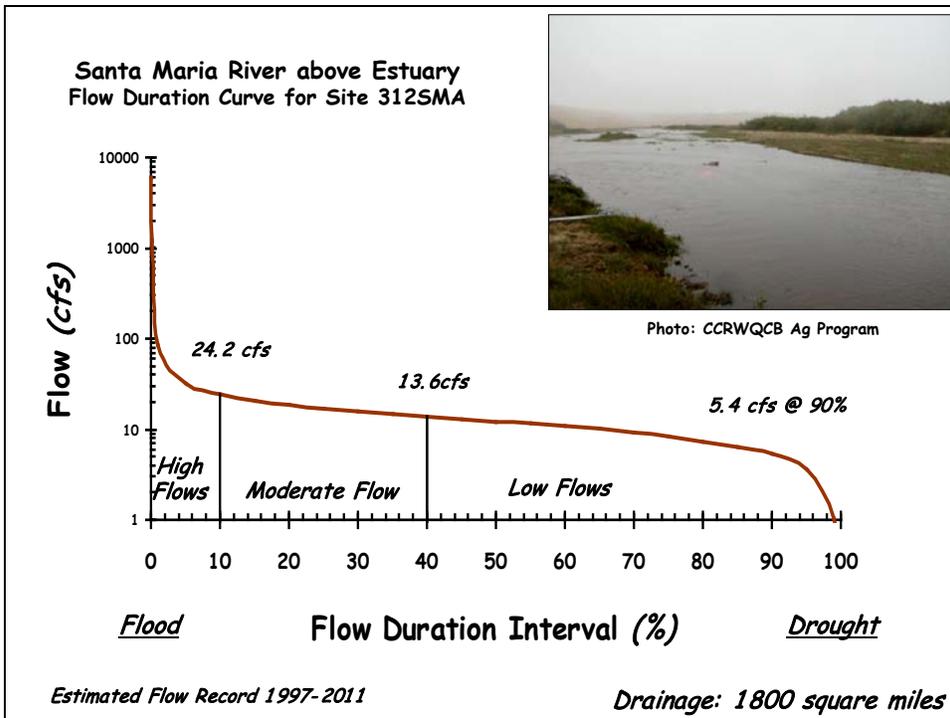
Figure 1-3 Flow Duration Curve Santa Maria River above the Estuary

1.3   Load Duration Curves

A load duration curve is the allowable loading capacity of a pollutant, as a function of flow. The flow duration curve is transformed into a load duration curve by multiplying the flow by the water quality objective and a conversion factor. The water quality objective that staff selected to calculate the load duration curves was the guidance criteria of 0.025 µg/L for chlorpyrifos and 0.160 µg/L for diazinon (CDFG, 2000; CDFG, 2004). The load duration curve is thus calculated by multiplying the flow at the given flow exceedance percentile, by the instantaneous chlorpyrifos or diazinon criteria and unit conversion factors; therefore the loading capacity for chlorpyrifos is:

Loading capacity (grams/day) = 0.025 µg/L (criteria) * Q (cfs) * 2.447 (unit conversion factor)

The load duration method essentially uses an entire stream flow record to provide insight into the flow conditions under which exceedances of the water quality objective occur. Exceedances that occur under low flow conditions are generally attributed to loads delivered directly to the stream such as straight pipes or some other form of direct discharge. Exceedances that occur under high flow conditions are typically attributed to loads that are delivered to the stream in stormwater runoff. Exceedances occurring under during normal flows can be attributed to a combination of runoff and direct deposits.

The load duration curve is derived from the flow duration curves and water quality monitoring data, as outlined in Section 1.1 Points plotting above the curve represent loads deviating from the water quality objective (the allowable load, loading capacity). Those plotting below the curve represent compliance with standards and represent loads below the maximum loading capacity.

A load duration curve (LDC) considers how flow conditions relate to a variety of pollutant sources, and therefore load duration curves can be useful in differentiating between possible loading from point and nonpoint sources (see Table 1). For example, observed loads at high to moderate flows appear to suggest that non-point sources and stormwater flows are potential sources and observed loads at low flows appear to suggest direct point sources or irrigation return flows.

Table 1. Potential relationship between load duration curve and contributing sources

Contributing Source	Flow Regime-Load Duration Curve		
	High Flow	**Moderate Flow**	**Low Flow**
Direct Point Sources (pipe discharge, etc)			*H*
Direct Delivery (irrigation return flows, spills)		*M*	*H*
Sediment Resuspension	*H*	*M*	
Stormwater: Agricultureal runoff	*H*	*H*	
-Note: Color Shading = Potential relative importance of source area to contribute loads under given hydrologic condition **(H=High; M=Medium)** -Figure adapted from USEPA, Bruce Cleland, and Oregon Dept. of Environmental Quality			

The load duration curve itself can be established as the TMDL. The TMDL would be dynamic and based on flow. Essentially, the loading capacity is the load corresponding

to the flow selected along the curve. Alternatively, a static TMDL can be established based on the area beneath the TMDL curve, representing the loading capacity of the stream. The difference between this area and the area representing current loading conditions is the load that must be reduced to meet water quality standards.

1.3.1 Percent Reduction Goals

Load duration analysis included a "percent reduction" that was calculated for informational purposes only, to illustrate the difference between existing conditions and the loading capacity at the time the streams were sampled. The percent reduction for each impaired segment is provided in section 1.3.2.

A TMDL provides a foundation for identifying, planning, and implementing water quality-based controls to reduce both point and nonpoint source pollution. Though the data used to calculate the percent reductions may be considered "historical", it provides a representation of the existing FIB loads in the waterbodies over a range of hydrologic conditions. Therefore, the percent reduction *should not be viewed as the TMDL* but rather a goal to work towards in the implementation phase of the TMDL process with the ultimate goal being the restoration and maintenance of in-stream water quality so that beneficial uses are met. The percent reduction can be calculated as:

Percent reduction = [(existing load) - (allowable load)/(existing load)] *100

1.3.2 Determination of Loading Capacity and Existing Load

This section presents the load duration curves and estimates of existing loading for impaired waterbodies in the project area. Also presented for each impaired reach are tables displaying the likely major sources of bacterial loading to that waterbody. Based on the source analysis, the estimated relative contribution of each source category is qualified as follows: categories with >20% potential load contributions are defined as a High Contributor; 5%-20% a Moderate Contributor; <5% a Low Contributor.

In accordance with USEPA guidance (USEPA, 2007), and given that the instantaneous fecal coliform criterion states that no more than 10 percent of samples should exceed 400 MPN/100 ml, it is appropriate to evaluate existing loading as the 90th percentile of observed fecal coliform concentrations.

Staff used guidance from USEPA (2007) in using load duration curves to assess existing loads and flow-based assimilative capacity. Therefore, existing loading is conservatively calculated as the 90th percentile of measured fecal coliform concentrations under each hydrologic flow regime class multiplied by the flow at the middle of the flow exceedance percentile. The 90 percentile of measure loads is a more conservative estimate than using the median. For example, in calculating the existing loading under high flow conditions (flow exceedance percentiles = 0-10% percent), the 5th percentile exceedance flow is multiplied by the 90th percentile of fecal coliform concentrations measured within the 0-10th percentile flow class. Similarly, the middle percentile (25%) of the moderate flow regime was used, to assess existing loads at moderate flow (10-40th percentile flow class). Low flows were handled a little differently. Many project area streams are ephemeral, and flow is not observed 100% of the time. In addition, water quality data is rarely available for the 80 to 100th percentile flows, which correspond

either to dry stream bed conditions, or extremely limited flows. Therefore, the existing loading at low flow conditions is multiplied by the flow at the 60th percentile flow.

For a graphical example of how existing loads and flow-based assimilative capacities (TMDLs) are determined, refer to Figure 2.
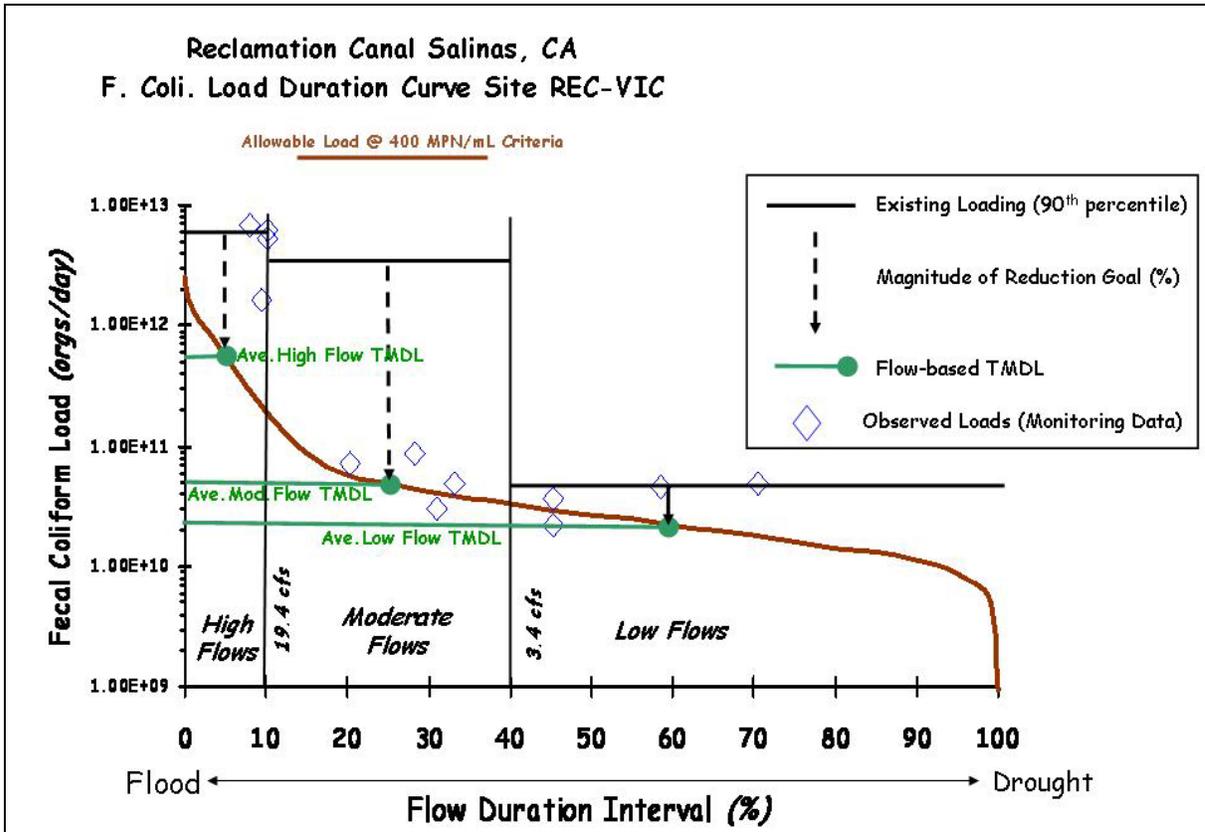
Figure 1-4. Example assessment of existing load, percent reduction goal, and flow-based TMDLs.

The load duration curves, and assessment of existing loads and flow based TMDLs for each impaired waterbody in the Project Area are presented in Section 10 in the TMDL FIB Report. The load duration curves are constructed for monitoring points located closest to the downstream confluence, or river mouth of the associated waterbody. This ensures that the loading capacity of the waterbody, and that all or most source contributions in the watershed drainage are potentially represented.
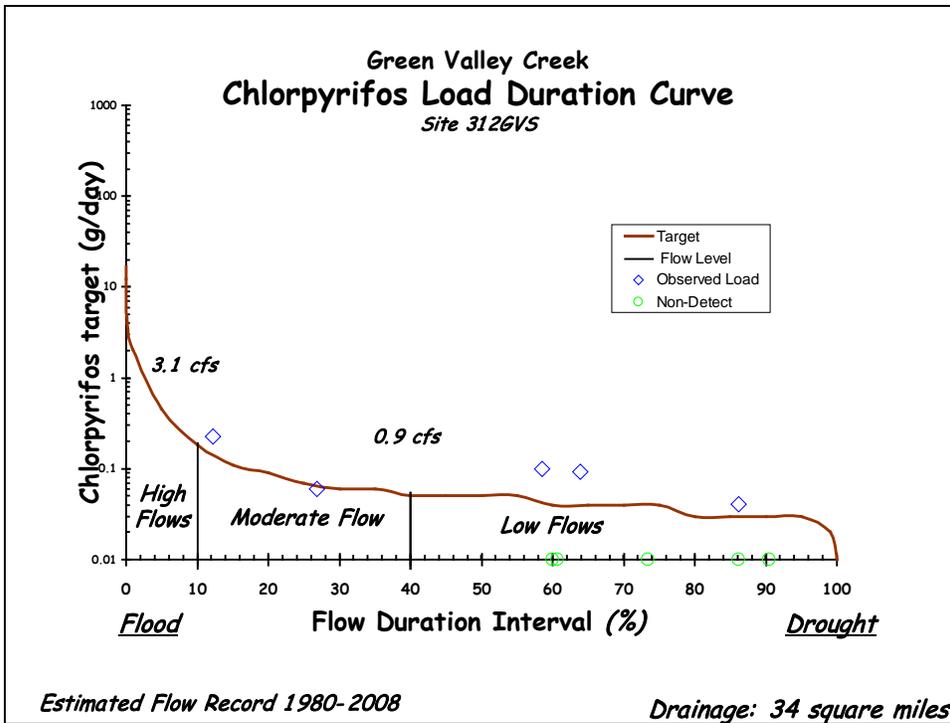
Figure 1-5 Chlorpyrifos Load Duration Curve,Green Valley Creek (312GVS)
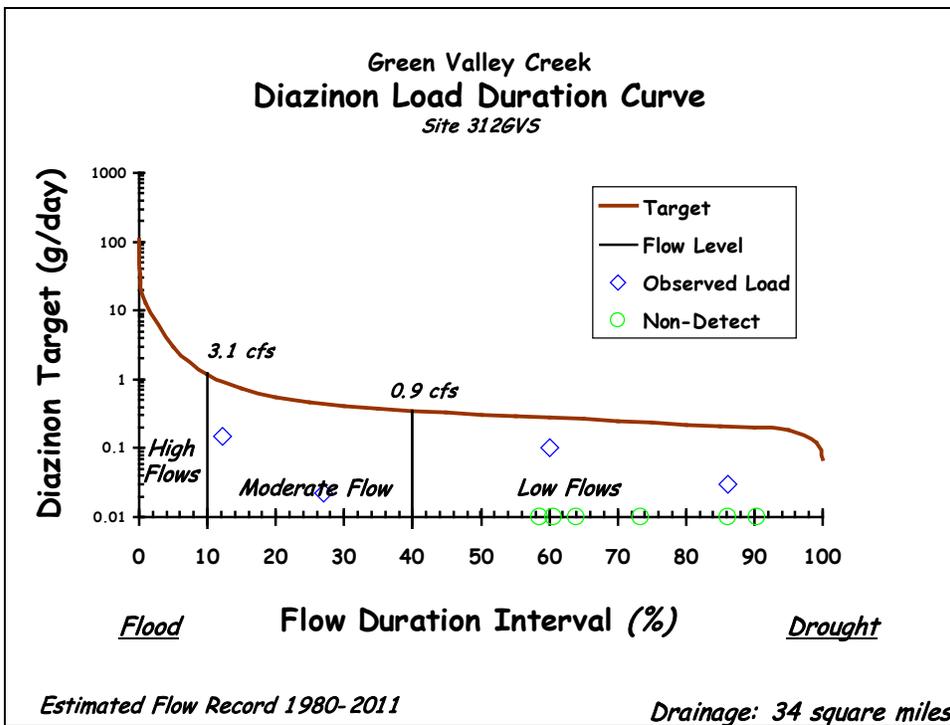
Figure 1-6 Diazinon Load Duration Curve, Green Valley Creek (312GVS)
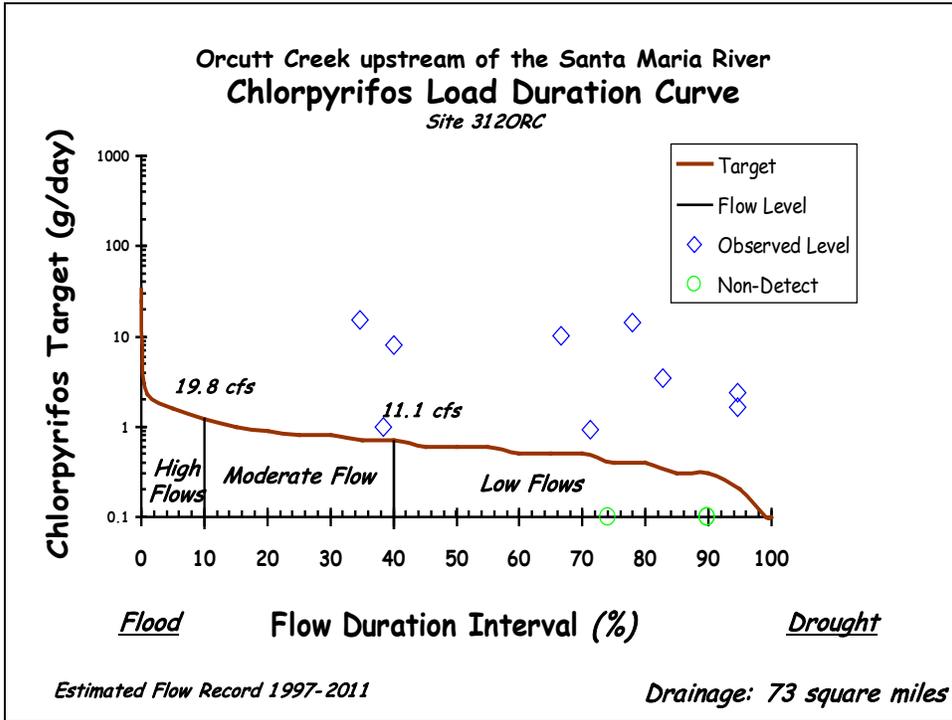
Figure 1-7 Chlorpyrifos Load Duration Curve, Orcutt Creek (312ORC)
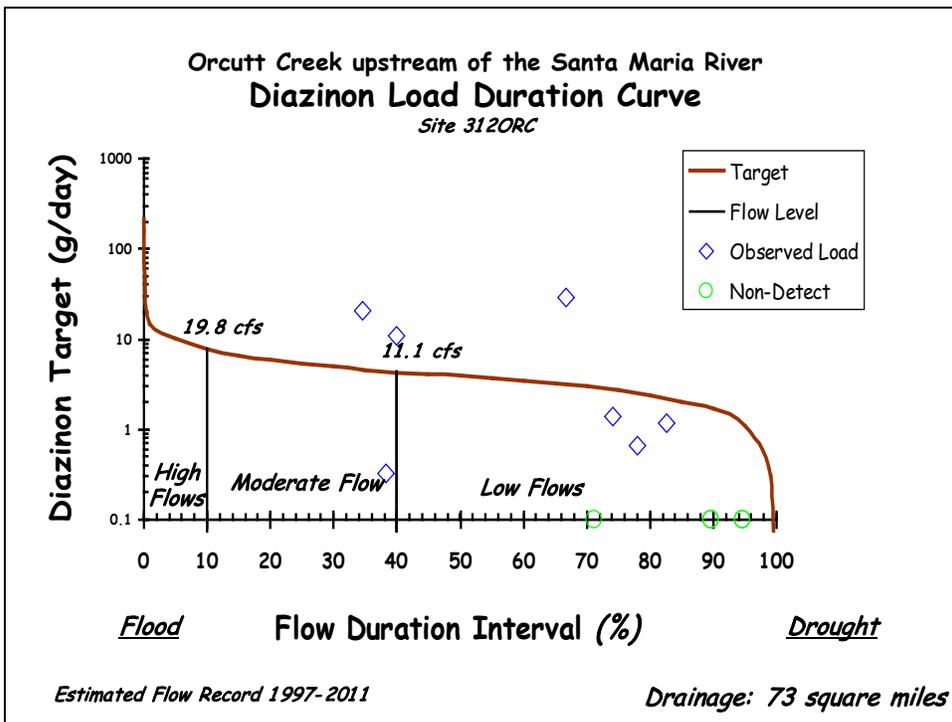
Figure 1-8 Diazinon Load Duration Curve, Orcutt Creek (312ORC)
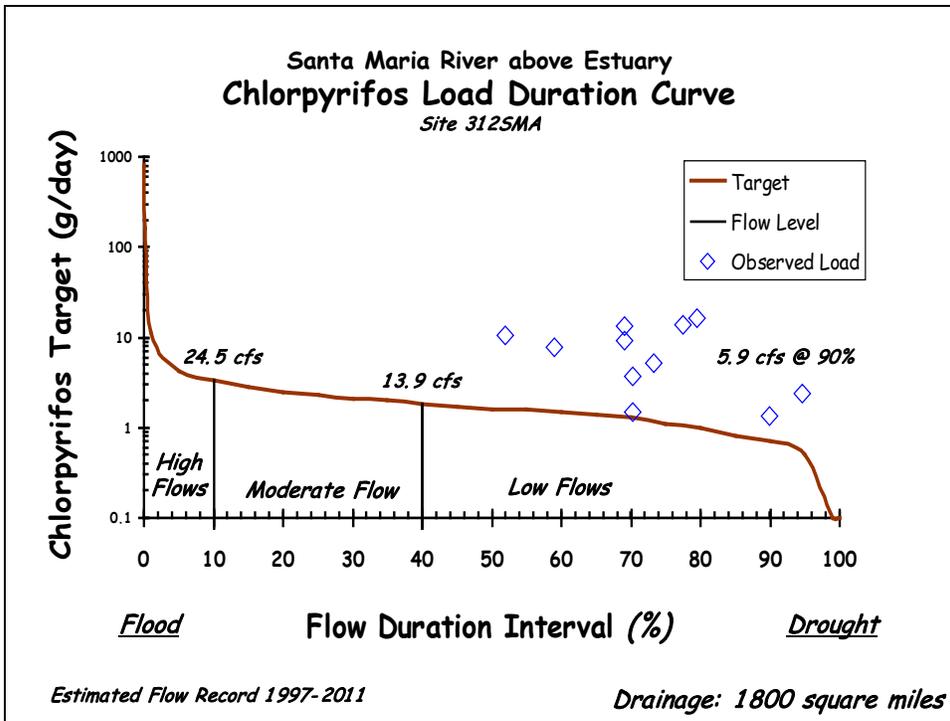
Figure 1-9 Chlorpyrifos Load Duration Curve, Santa Maria River (312SMA)
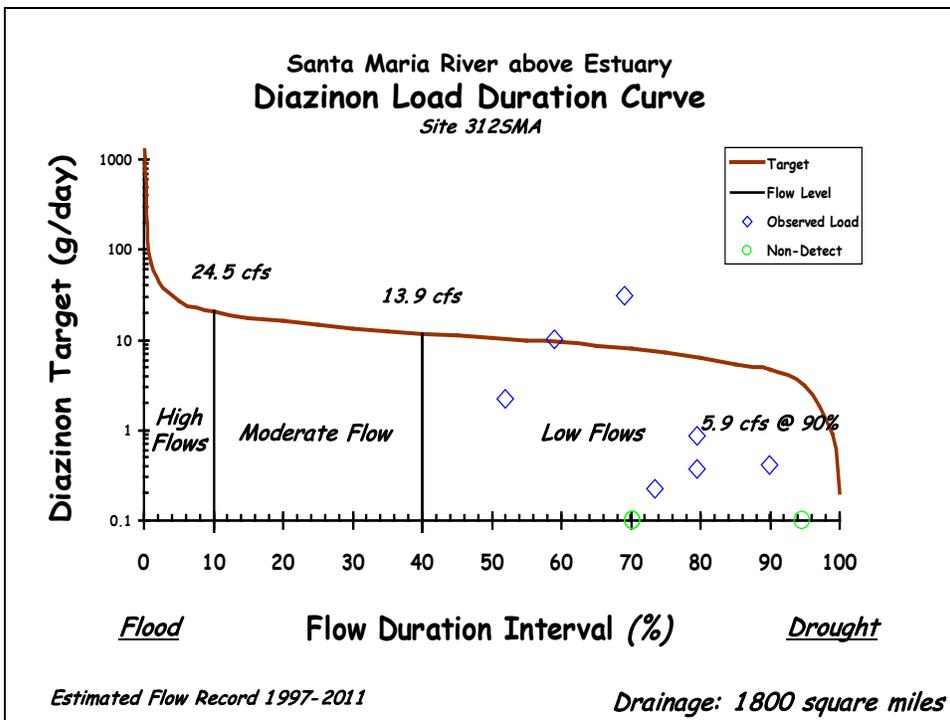
Figure 1-10 Diazinon Load Duration Curve, Santa Maria River (312SMA)