Back to Basics – Using Hydrology to Communicate Data as Information

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Biographical Sketch of Author

Bruce Cleland is a TMDL *"Circuit Rider"* for the Clean Water Foundation, where he specializes in providing detailed technical assistance, technical education, and information transfer to States to assist them in their efforts to develop TMDLs. He is currently on loan to ACWF from EPA's Seattle Office where he worked in the water quality program, including over 10 years as the Region's TMDL Coordinator. At Region 10, Bruce was also involved with the ambient water quality monitoring program, the nonpoint source program, and the permits / compliance program.

Abstract

With the wide array of issues facing water quality managers, limited resources, and the complex, inter-related nature of water programs – the "two Ps": *practical* approaches and *partnerships* – are critical to successful watershed planning and implementation. Dependable tools are needed, which promote effective communication between analysts, planners and implementers, so that actions will lead to measurable water quality improvements. Over the past several years, basic hydrology in the form of flow duration curves has been used to support the development of TMDLs.

Flow duration curve analysis identifies intervals, which can be used as a general indicator of hydrologic condition (i.e. wet versus dry and to what degree). Duration curves help refine assessments by expanding the characterization of water quality concerns, linking concerns to key watershed processes, and prioritizing source evaluation efforts. The extended use of monitoring information using duration curves offers an opportunity for enhanced targeting, both in field investigation efforts and implementation planning.

Duration curves provide another way of presenting water quality data, which characterizes concerns and describes patterns associated with impairments. This framework can help elevate the importance of monitoring information to stakeholders, which in turn can encourage locally driven data collection efforts (e.g. through watershed groups, conservation districts, point sources). As an assessment and communication tool, duration curves can also help narrow potential debates, as well as inform the public and stakeholders so they become engaged in efforts to improve water quality. This presentation will use several examples to illustrate opportunities where duration curves can strengthen watershed assessments and enhance the water quality management process.

INTRODUCTION

With the wide array of issues facing water quality managers, limited resources by all involved with watershed management, and the complex, inter-related nature of water programs – the "two Ps": *practical* approaches and *partnerships* – are critical to successful watershed planning and implementation. On the practical side, water quality assessments must overcome the challenge of translating detailed technical concepts and data into *"plain English"*. On the partnership side, key stakeholders must be engaged in the process, so that meaningful results with measurable improvements are achieved. Dependable tools are needed, which communicate technical data as information so that it becomes an important part of finding solutions. Over the past several years, basic hydrology in the form of flow duration curves has been used to support TMDL development. These curves can help refine assessments by expanding the characterization of water quality concerns, linking concerns to key watershed processes, and prioritizing source evaluation efforts. The extended use of monitoring information using duration curves offers an opportunity for enhanced targeting, both in field investigation efforts and implementation planning.

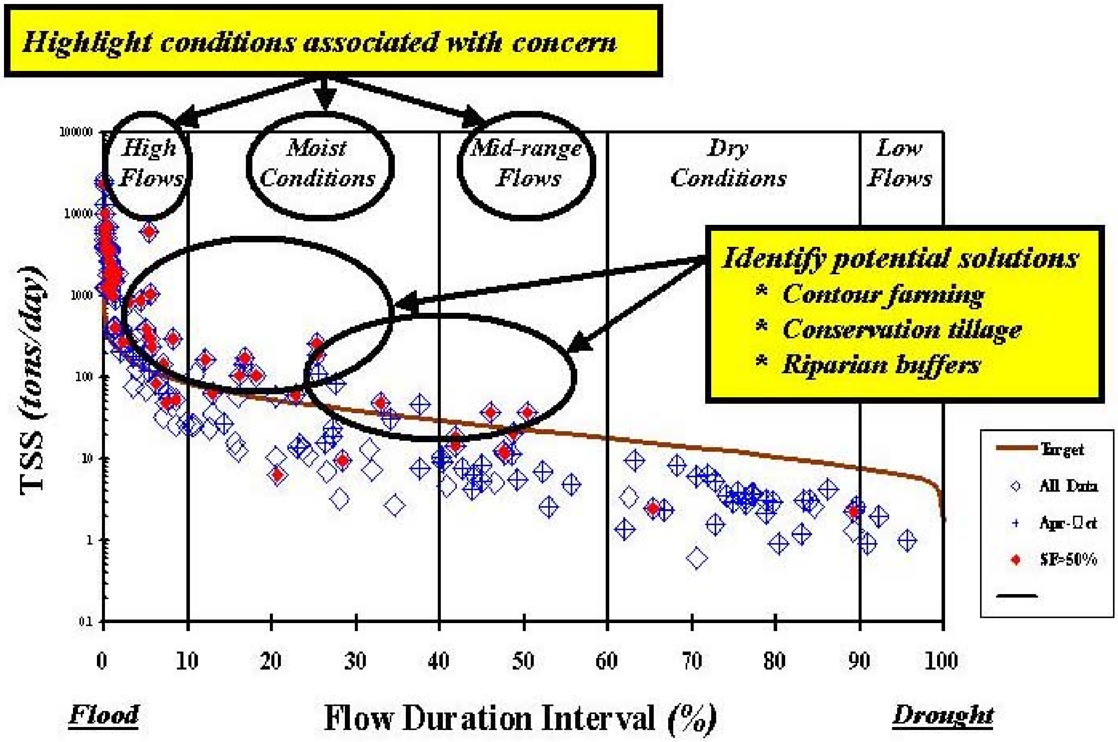
Duration curve analysis identifies intervals, which can be used as a general indicator of hydrologic condition (i.e. wet versus dry and to what degree). This indicator, when combined with other basic elements of watershed planning, can help point problem solution discussions towards relevant watershed processes, important contributing areas, and key delivery mechanisms. These are all major considerations when identifying those controls that might be most appropriate and under what conditions. Duration curves also give a context for evaluating both monitoring data and modeling information. Water quality monitoring data used in a duration curve framework can support watershed planning by providing a better description of water quality concerns with a focus on solution development.

Communicating Technical Data

An advantage of the duration curve framework is its ability, as a simple communication tool, to help answer questions that are a basic part of the problem-solving process. The following example briefly illustrates the *"added value"* that duration curves can provide. Figure 1 depicts a load duration curve developed for a watershed where sediment is causing impairments to resident trout populations. This load duration curve was developed to look at several issues. The first was to better characterize conditions surrounding water quality concerns. The second involved the relative importance of point sources in light of the timing of sediment load concerns. The third focused on the type of management practices (BMPs) that would be most effective.

As indicated in Figure 1, duration curves can be a very useful tool to characterize water quality concerns and to describe patterns associated with the impairment. The use of duration curve zones (e.g. high flows, moist conditions, etc.) provides a method for communicating technical information in a way that easily conveys conditions associated with problems. The results of the quick duration curve analysis shown in Figure 1 indicate point sources, which generally tend to be most significant during low flows, do not appear to be major contributors. Practices that target delivery reduction (riparian buffers) and source control (contour farming, conservation tillage) under mid-range flows and moist conditions appear to offer the greatest benefit.

***Figure 1*.** Example Load Duration Curve



The concept of grouping water quality data based on flow conditions is not new. A duration curve framework simply provides a way to organize the information. A common challenge faced by water quality analysts is to explain how monitoring data might translate into potential actions. A duration curve framework can be used to summarize targets and highlight implementation opportunities that correspond to flow conditions. As a communication tool, the graphic display combined with other basic elements of watershed planning can help guide problem-solving discussions in a meaningful way. Duration curves, like any other analytical tool, are not a substitute for field reconnaissance work. Good watershed assessment, which leads to effective management plans, cannot be limited to "desk-top" exercises. Grounded, fact-finding is needed to examine what is actually going on in the watershed. Duration curves can, however, highlight relevant watershed conditions, processes, and potential solutions.

Engaging Stakeholders

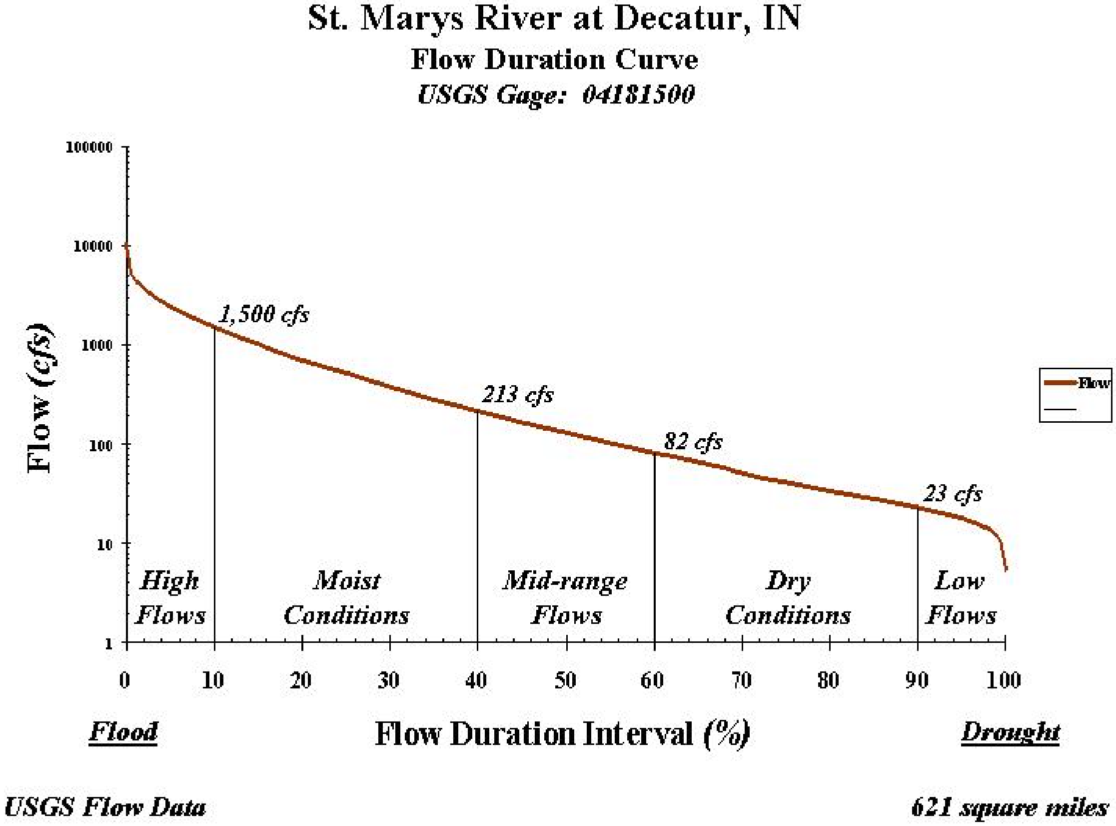
Public involvement is fundamental to successful water quality planning and implementation. Duration curves provide another way of presenting water quality data, which characterizes concerns and describes patterns associated with impairments. As a communication tool, this framework can help elevate the importance of monitoring information to stakeholders. This in turn can encourage locally driven data collection efforts (e.g. through watershed groups, conservation districts, point sources). The extended use of monitoring information using duration curves offers an opportunity for enhanced targeting, both in field investigation efforts and implementation planning. In looking for solutions, duration curves support a problem-solving framework by identifying targeted areas, targeted programs, targeted activities, and targeted participants. As an assessment and communication tool, duration curves can help narrow potential debates, as well as inform the public and stakeholders so they become engaged in the process.

DEVELOPMENT OF DURATION CURVES

Water resource planners have utilized stream flow data for many years to support a variety of activities ranging from development of public water supplies to fisheries management and flood control. A network of river gaging stations and the published data obtained from their operation supports these water resource management efforts *(Leopold, 1994)*. Information on river flows across the United States is readily available from the U.S. Geological Survey. Due to the wide range of variability that can occur in stream flows, hydrologists have long been interested in knowing the percentage of days in a year when given flows occur. The percentage of time during which specified flows are equaled or exceeded may be evaluated using a flow duration curve. Flow duration analysis looks at the cumulative frequency of historic flow data over a specified period. The duration analysis results in a curve, which relates flow values to the percent of time those values have been met or exceeded, so that the full range of stream flows is considered. Low flows are exceeded a majority of the time, while floods are exceeded infrequently.

The development of a flow duration curve typically uses daily average discharge rates, which are sorted from the highest value to the lowest, as illustrated in Figure 2. In this example, a flow duration interval of sixty associated with a stream discharge of 82 cubic feet per second (cfs) implies that sixty percent of all observed daily average stream discharge values equal or exceed 82 cfs.

Figure 2. General Form of the Flow Duration Curve



Extending Duration Curves to Water Quality Assessments

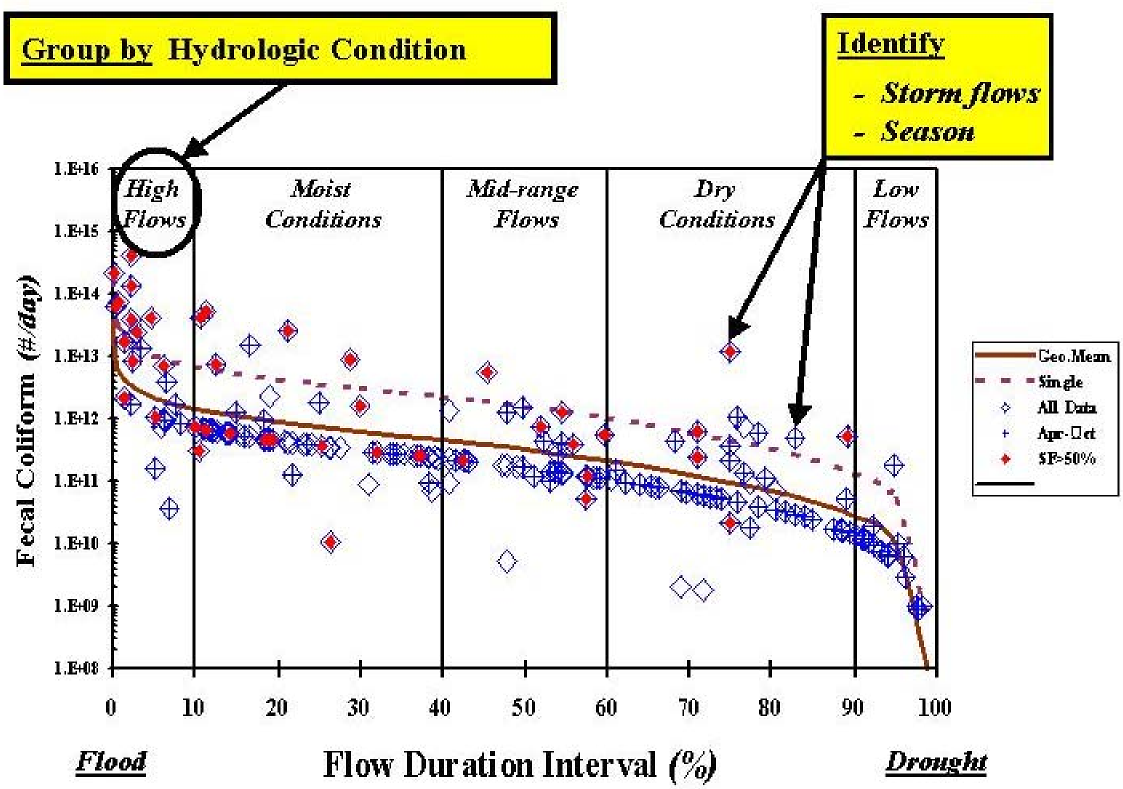
An advantage of the duration curve framework is its ability, as a simple communication tool, to link potential implementation efforts to the hydrologic condition of the watershed in a way that can improve targeting of watershed restoration activities. The approach allows relationships between source area / delivery mechanisms and the corresponding watershed response to be examined in the context of hydrologic conditions. A duration curve framework can support water quality assessments by:

* enhancing the characterization of water quality concerns
* linking concerns to key watershed processes
* prioritizing source assessment efforts
* identifying potential solutions

CHARACTERIZING WATER QUALITY CONCERNS

A duration curve framework is particularly useful in providing a simple display, which describes the flow conditions under which water quality criteria are exceeded. Stiles *(2002)* describes the development of a load duration curve using the flow duration curve, the applicable water quality criterion, and the appropriate conversion factor. Ambient water quality data, taken with some measure or estimate of flow at the time of sampling, can be used to compute an instantaneous load. Using the relative percent exceedance from the flow duration curve that corresponds to the stream discharge at the time the water quality sample was taken, the computed load can be plotted in a duration curve format *(Figure 3)*.

Figure 3. Ambient Water Quality Data Using a Duration Curve Framework



By displaying instantaneous loads calculated from ambient water quality data and the daily average flow on the date of the sample (expressed as a flow duration curve interval), a pattern develops, which describes the characteristics of the impairment. Loads that plot above the curve indicate an exceedance of the water quality criterion, while those below the load duration curve show compliance. The pattern of impairment can be examined to see if it occurs across all flow conditions, corresponds strictly to high flow events, or conversely, only to low flow conditions.

Duration Curve Zones

Flow duration curve intervals can be grouped into several broad categories or zones, in order to provide additional insight about conditions and patterns associated with the impairment. For example, the duration curve could be divided into five zones: one representing *high flows*, another for *moist conditions*, one covering median or *mid-range flows*, another for *dry conditions*, and one representing *low flows*. Impairments observed in the low flow zone typically indicate the influence of point sources, while those further left generally reflect potential nonpoint source contributions. This concept is illustrated in Figure 3. Data may also be separated by season (e.g. spring runoff versus summer base flow). For example, Figure 3 uses a "+" to identify those ambient samples collected during primary contact recreation season (April – October).

The utility of duration curve zones for pattern analysis can be further enhanced to characterize wet-weather concerns. Some measure or estimate of flow is available to develop the duration curves. As a result, stream discharge measurements on days preceding collection of the ambient water quality sample may also be examined. This concept is illustrated in Figure 3 by comparing the flow on the day the sample was collected with the flow on the preceding day. Any one-day increase in flow (above some designated minimum threshold) is assumed to be the result of surface runoff (unless the stream is regulated by an upstream reservoir). In Figure 3, these samples are identified with a red shaded diamond. Similarly, stream discharge data can also be examined using hydrograph separation techniques to identify storm flows. This is also illustrated in Figure 3. Water quality samples associated with storm flows (SF) greater than half of the total flow (SF>50%) are uniquely identified on the load duration curve, again with a red shaded diamond.

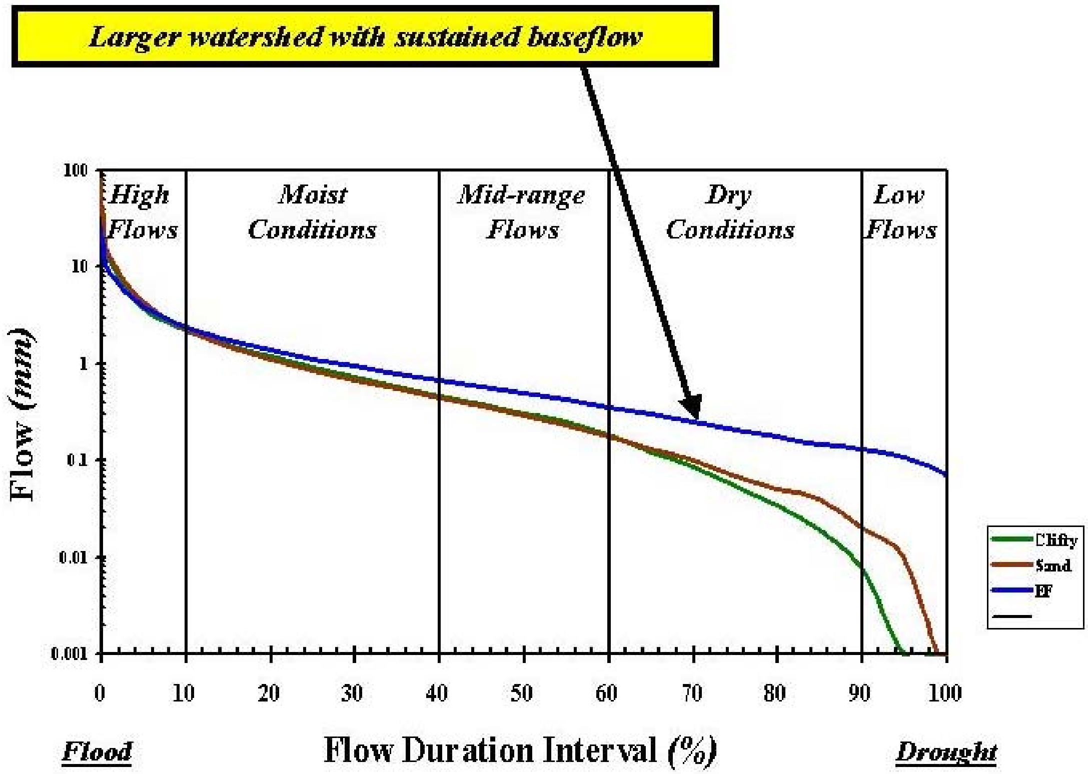
LINKING CONCERNS TO KEY WATERSHED PROCESSES

Duration curves can be a very useful tool to characterize water quality concerns and to describe patterns associated with the impairment. The use of duration curve zones provides a method for communicating technical information in a way that easily conveys conditions associated with problems. Furthermore, flow data used to develop duration curves can be employed, either by simple comparison or through hydrograph separation, to identify wet-weather events that may result from surface runoff or storm flows. Duration curves also provide a framework, which can link water quality concerns to key watershed processes that may be important considerations in watershed planning. Basic principles of hydrology can help identify the relative importance of factors such as water storage or storm events, which subsequently affect water quality.

Flow Duration Curve Relationships

An analysis of relationships between flow duration curves from different sites can provide some insight into factors that may affect the movement of water in a drainage area. The shape of the flow duration curve reflects the ability of a basin to store water temporarily in the ground and to release it later as contributing flow *(Leopold, 1994)*. Systems with limited groundwater storage capacity (e.g. areas that are impervious) tend to have steep slopes at the low-flow end of the duration curve. Typically, a steeply sloping duration curve is characteristic of a highly variable system, where stream flow is largely driven by direct runoff. Wet-weather events are going to exert a major effect on the delivery of pollutant loads to these systems. In contrast, streams that have large amounts of water in storage (e.g. from groundwater or wetland complexes) tend to have flat slopes at the low-end. Typically, a flatter sloping duration curve is characteristic of streams draining areas with high storage capacity that sustains or equalizes flow. Figure 4 uses a unit area flow duration curve to illustrate these differences. Similar analyses with unit area flow duration curves have been used to highlight the effect of human activities on watershed processes, such as groundwater pumping or low head in-stream structures intended to maintain upstream water levels.

Figure 4. Use of Flow Duration Curves to Examine Watershed Storage Processes



Applications with Water Quality Monitoring Data

A duration curve framework can also utilize ambient monitoring data to help link water quality concerns to key watershed processes. This potential application is illustrated with volunteer monitoring data that was collected for consideration in watershed planning efforts. A duration curve (DC) framework was used to conduct a preliminary analysis of the data. This "*quick DC*" assessment points out several interesting patterns in the data, which provide some valuable insights into watershed processes that may affect turbidity.

Figure 5 depicts turbidity data from a reference site. Median concentrations in each flow duration zone are identified with a dashed line. Figure 6 shows the results of turbidity monitoring from a location in the watershed where there are sediment concerns. The zone median concentrations (ZMC) for both sites are displayed in Figure 6 for comparison. It is interesting to note that in the dry, mid-range, and moist condition zones, the patterns for both sites are comparable (considering the log scale). However, in the high flow zone, there is a distinct difference in observed turbidity patterns between the sites. Analysis of this monitoring data suggests watershed processes and management activities that affect turbidity at high flows should be strongly considered in water quality plan development. In this case, streambank erosion, which generally delivers sediment under high flows, may be a factor that could exert a significant influence.

Figure 5. Duration Curve for Turbidity at Reference Site

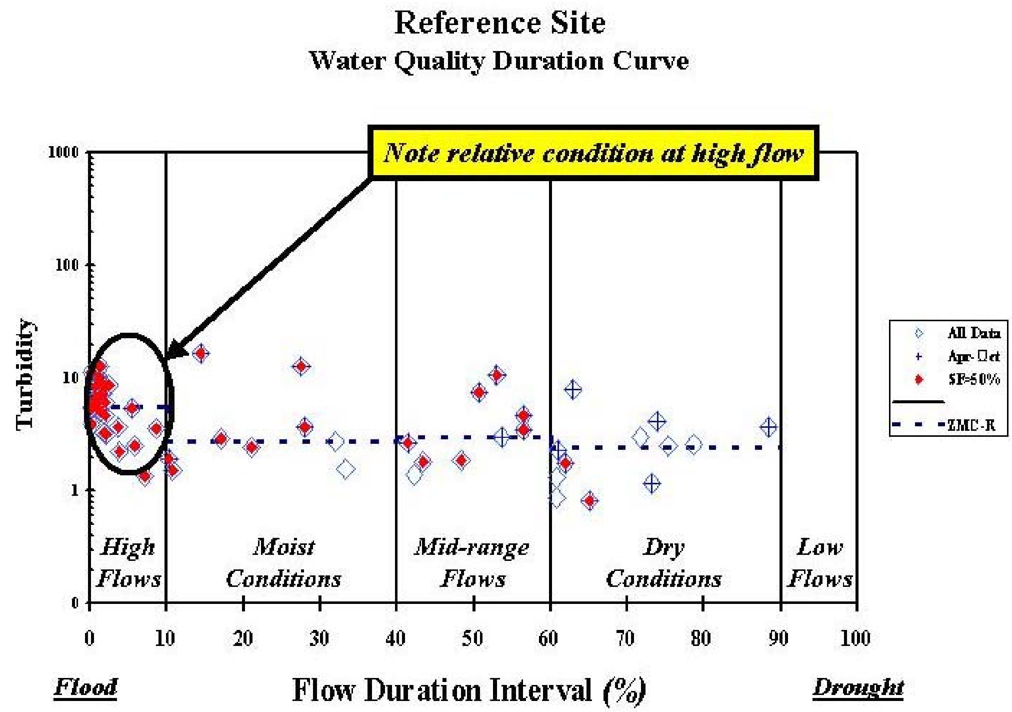
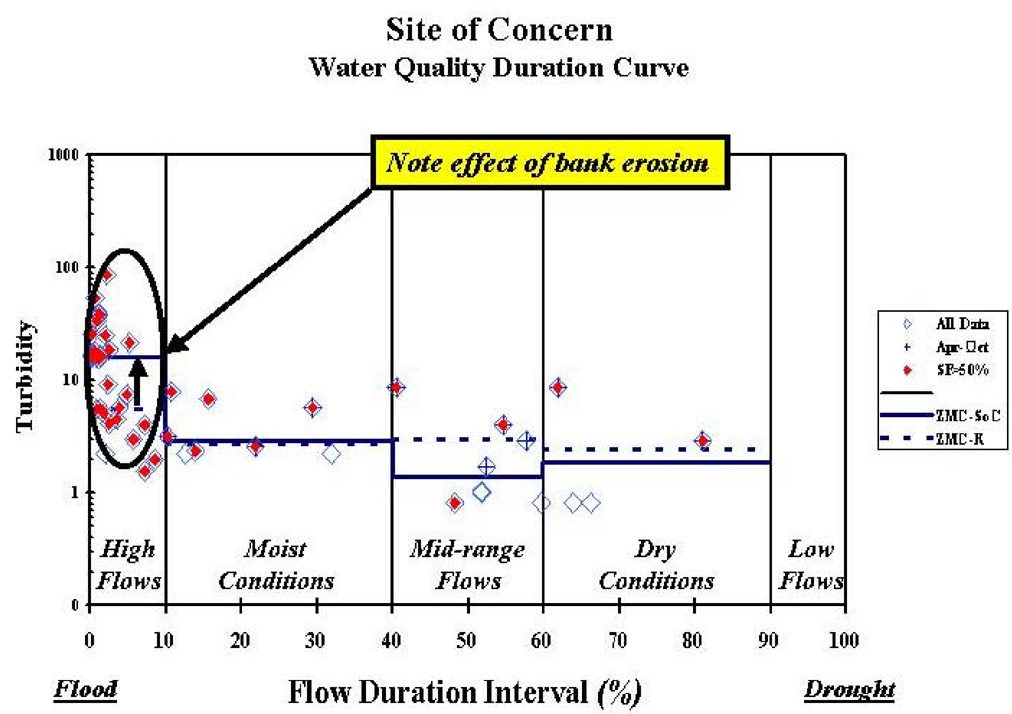


Figure 6. Duration Curve for Turbidity at Site of Concern



Use with Water Quality Models

Duration curves provide a way to approach water quality assessments. Several examples have been used to illustrate how duration curves can be used to provide a context for analyzing ambient water quality data. The duration curve framework can also be used to examine information produced from a source loading analysis or from a water quality model, such as HSPF *(Figure 7)*.

Water quality values calculated with a dynamic model, for instance, can be associated with daily average flow rates. This information can be used to determine a corresponding flow duration interval, and then develop a load duration curve based on the model output. Load duration curves developed from model output provide an alternative method, which can be used for communicating information to watershed groups.

A load duration curve derived from a water quality model can also be compared to a LDC based on ambient water quality monitoring data *(Figure 8)*. This type of analysis can either confirm model assumptions or help prioritize source assessment needs. Looking at Figures 7 and 8, the model appears to overestimate loads under dry and low flow conditions, when compared to the actual ambient water quality data. The model also appears to underestimate loads, when examining moist and mid-range flow conditions. Investigating this discrepancy should be a high source assessment priority, as it could affect management decisions regarding the most effective implementation strategies.

Source Tracking Information

The increased use of source tracking methods offers another opportunity to utilize a duration curve framework in prioritizing source assessment efforts. For example, bacteria source tracking (BST) data is being collected to determine the potential origin of pathogens observed in water quality samples. Duration curves provide another view of BST information, in a way that considers the hydrologic condition of the watershed and potential delivery mechanisms.

Figure 9 depicts BST data using the Antibiotic Resistance Analysis (ARA) method. In this example, the sample point represents a unit area load (e.g. the estimated load divided by the drainage area) for purposes of comparing data from different sites in the watershed. Each point is also identified with source categories from ARA results (the letter on the left denotes the dominant source; the letters inside the parentheses denote other sources detected above a minimum threshold). The role of the duration curve framework for this application is to examine patterns. In Figure 9, BST patterns observed under mid-range and moist conditions can help prioritize follow-up wet-weather assessments. Conversely, BST patterns observed under dry and low flow conditions can help identify direct bacteria inputs to the stream.

Figure 7. Duration Curve Developed Using HSPF Output

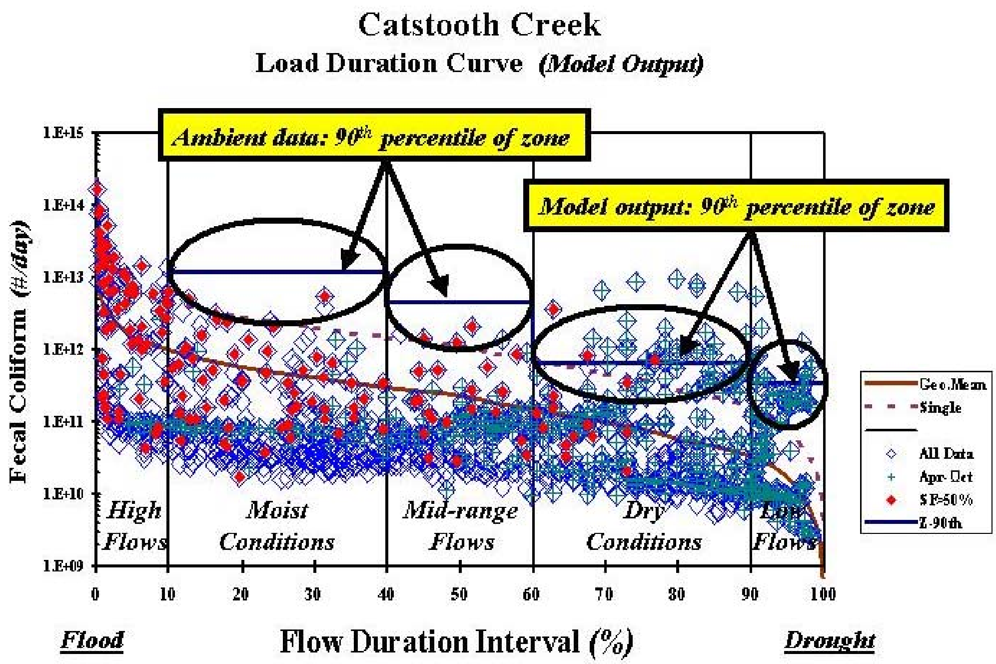


Figure 8. LDC from Ambient Data for Comparison to Model Results

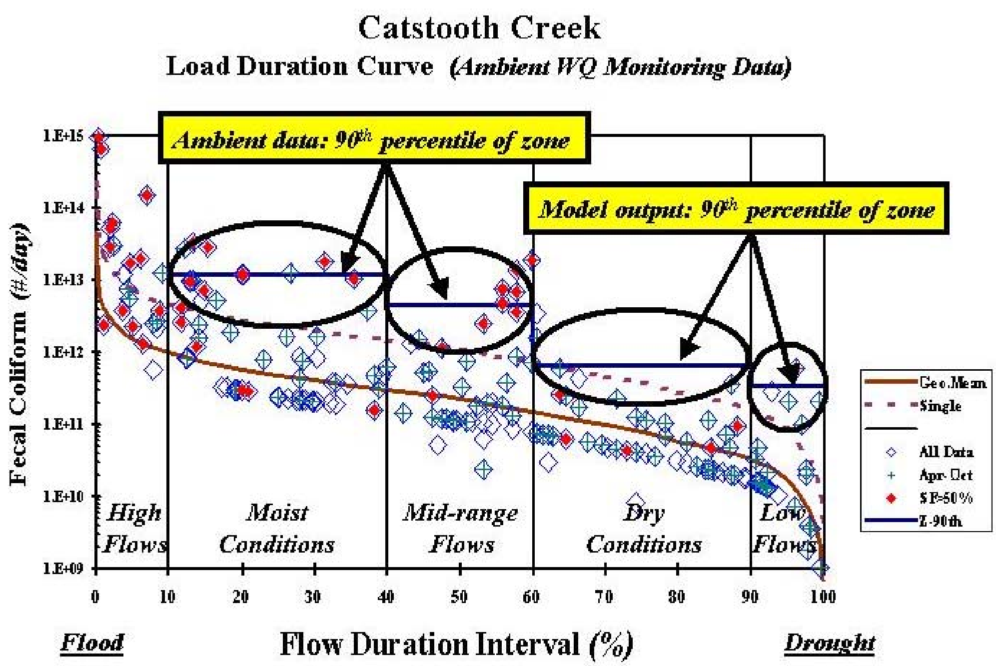
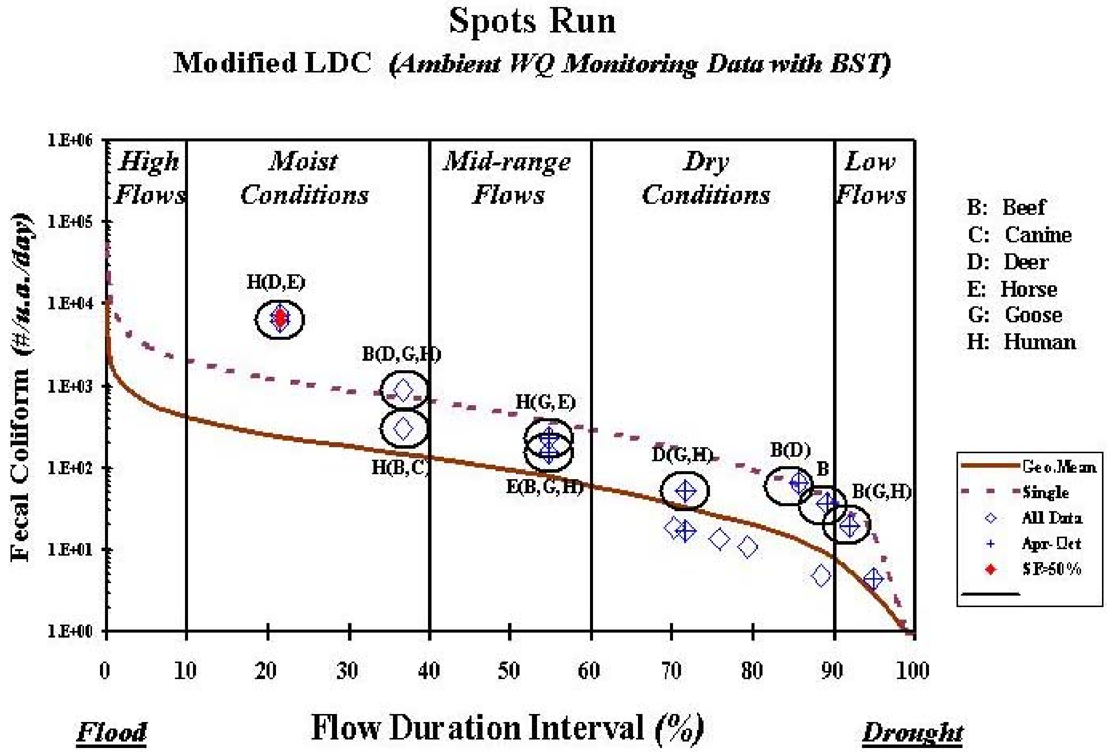


Figure 9. BST Information Displayed Using Duration Curve Framework



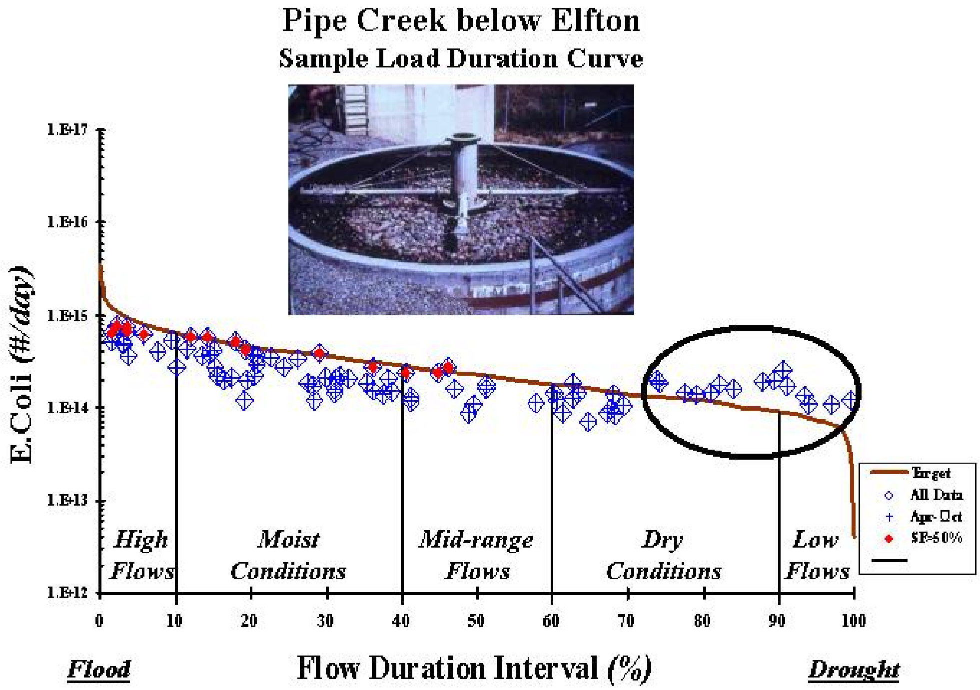
IDENTIFYING POTENTIAL SOLUTIONS

Duration curves offer an opportunity for enhanced targeting in water quality restoration efforts. In particular, duration curves can add value to the assessment process by identifying:

* targeted participants (e.g. NPDES permitees) at critical flow conditions;
* targeted programs (e.g. Conservation Reserve Program);
* targeted activities (e.g. conservation tillage or contour farming); and
* targeted areas (e.g. bank stabilization projects).

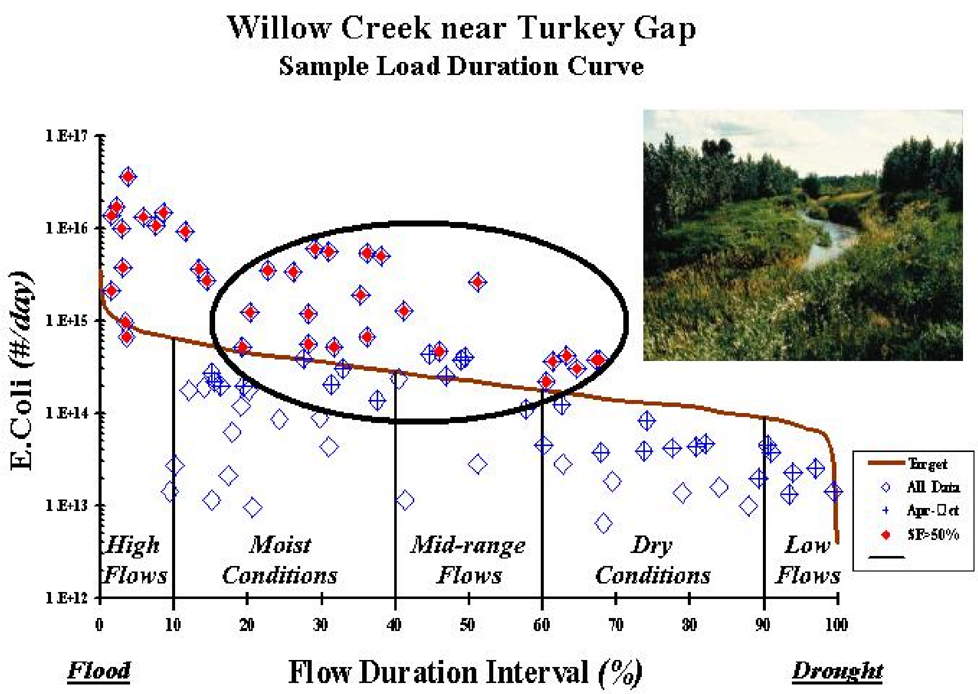
Figure 10 represents the first of several hypothetical examples to illustrate the potential use of duration curves, both as a diagnostic indicator and as a communication tool for targeting in the water quality assessments. The target curve in Figure 10 is derived using flow duration intervals that correspond to stream discharge values and numeric criteria for E. Coli. The area circled on the right side of the duration curve represents hydrologic conditions where the target is exceeded. In this example, wastewater treatment plants exert a significant influence at low flows. Thus, duration curves support water quality restoration efforts by identifying *targeted participants*, in the case of Figure 10, point sources. Figure 11 illustrates the added value duration curves can provide by highlighting potential contributing areas. As seen in this hypothetical example, problems start to develop under mid-range flow and sometimes dry conditions. In this case, the increased load may be the result of pollutant delivery associated with rainfall and runoff from riparian areas. In more urban watersheds, runoff from impervious areas could also contribute flow and pollutants in response to light rain, exhibiting a pattern similar to Figure 11. Duration curves can be used as a diagnostic tool, which supports water quality restoration efforts by identifying *targeted programs*, namely those focused on riparian protection. In agricultural areas, like Figure 11, this might include activities such as the Conservation Reserve Program (CRP) and Conservation Reserve Enhancement Program (CREP).

Figure 10. Duration Curve as General Indicator of Hydrologic Condition



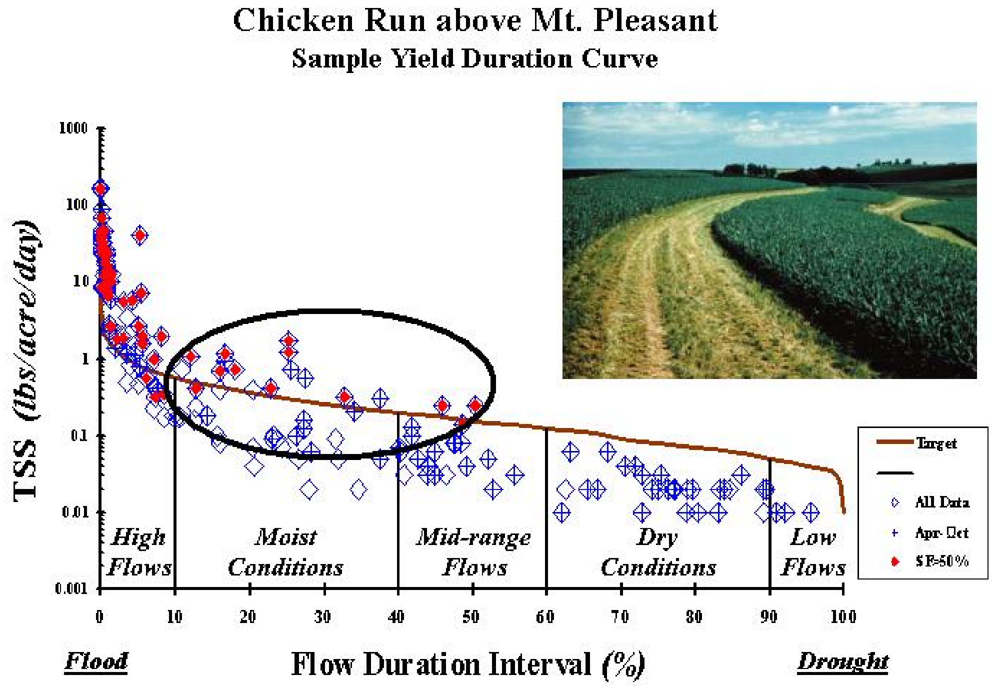
TARGETED Participants: ***Point Sources***

Figure 11. Duration Curve with Contributing Area Focus



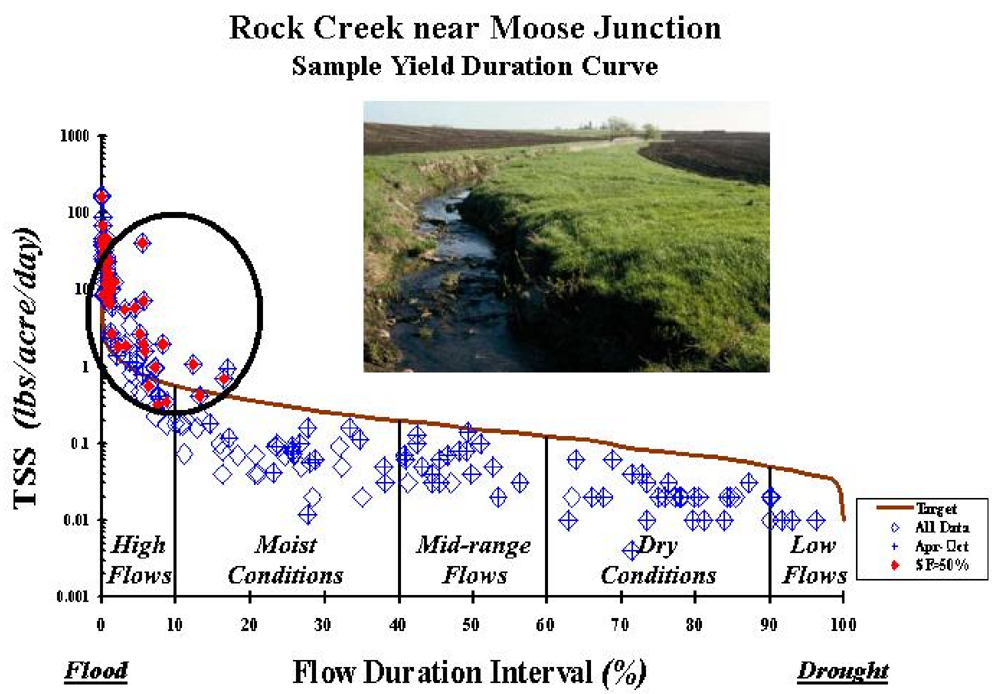
TARGETED Programs: ***Riparian Buffers (e.g. CRP, CREP)***

***Figure 12*.** Duration Curve with Contributing Area Focus



TARGETED Activities: ***Contour Strips, Conservation Tillage***

***Figure 13*.** Duration Curve with Delivery Mechanism Focus



TARGETED Areas: ***Streambank Erosion, Bank Stability***

The focus on contributing areas is further illustrated with another hypothetical example, shown in Figure 12, where total suspended solids is the pollutant of concern. Here, the duration curve is expressed in terms of yield to show how distributions derived from a flow duration curve can be extended to other measures, again as a simple targeting tool. In the Chicken Run example *(Figure 12)*, observed values only exceed the target when the hydrologic condition of the watershed is below 55 (generally higher flows). Chicken Run is also an agricultural watershed. Wet-weather events expected to deliver pollutants under moist conditions are generally associated with more saturated soils. In addition to riparian areas, a larger portion of the watershed drainage area is potentially contributing runoff. In this case, consideration might be given to *targeted activities* such as conservation tillage, contour strips, and grassed waterways. Figure 13 illustrates another hypothetical example, where delivery mechanisms could include streambank erosion processes. *Targeted areas* for water quality improvement might consider bank stabilization efforts.

SUMMARY

Dependable tools are needed, which communicate technical data as information so that it becomes an important part of finding solutions. Basic hydrology in the form of duration curves can help refine assessments by expanding the characterization of water quality concerns, linking concerns to key watershed processes, and prioritizing source evaluation efforts. Duration curve analysis identifies intervals that can be used as a general indicator of hydrologic condition (i.e. wet versus dry and to what degree). This indicator, when combined with other basic elements of watershed planning, can help point problem solution discussions towards relevant watershed processes, important contributing areas, and key delivery mechanisms. These are all major considerations when identifying those controls that might be most appropriate and under what conditions. Duration curves also give a context for evaluating both monitoring data and modeling information. Water quality monitoring data used in a duration curve framework can support watershed planning by providing a better description of water quality concerns with a focus on solution development.

A common challenge faced by water quality analysts is to explain how monitoring data might translate into potential actions. A duration curve framework can be used to summarize targets and highlight implementation opportunities that correspond to flow conditions. The concept of grouping water quality data based on flow conditions is not new. A duration curve framework simply provides another way to organize and present the information, which characterizes concerns and describes patterns associated with impairments. This framework can help elevate the importance of monitoring information to stakeholders. This in turn can encourage locally driven data collection efforts (e.g. through watershed groups, conservation districts, point sources). As an assessment and communication tool, duration curves can help narrow potential debates, as well as inform the public and stakeholders so they become engaged in the process.

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