FACT SHEET **No. 35**

Rangeland Watershed Program

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Exactly What is a 100-Year Event?

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When discussing hydrologic events, such as rainfalls or floods, one constantly hears terms such as the *100-year event*, *probability,* and *return period*. The umbrella that these terms fall under is known as *hydrologic frequency analysis*. Often these terms are used very loosely and are not understood by the person using them. What do these terms mean? Who cares? Where do these numbers come from? How much confidence can I put in these numbers? This fact sheet will provide a basic explanation for each question.

What do these terms mean?

Hydrologic frequency analysis is the evaluation of hydrologic records, such as rainfall or stream flow, to estimate how often (frequency) events of a given magnitude will occur or be exceeded. A *100-year event* is an event of such size that over a long period of time, much longer than 100 years, the average time between events of equal or greater size is 100 years. *Return period* is the average period of time expected to elapse between occurrences of events at a certain site. The return period for a 100-year event is 100 years. A 100-year event has a *probability* of 0.01 or 1% of being equaled or exceeded (exceedance probability) in any one year (probability = 1/return period = 1/100).

The size of a 100-year event is different for each watershed and depends upon climate and watershed characteristics. For instance, the 100-year 24-hour rainfall at Elko, NV, is approximately 2.5 inches while the 100-year 24-hour rainfall at Eureka, CA, is approximately 8 inches.

Return period is often misinterpreted to be a statistical guarantee that hydrologic events of a given size will occur on a predictable, fixed time schedule. Return period or probability estimate how likely an event is, but tell us nothing about when it will occur. The statement, “Well, we just had a 100-year flood, so we are safe for another 100 years,” is a complete misrepresentation of the definition of a 100-year event. The statement, “Well, we just had an *estimated* 100-year flood, so statistically we would not *expect* to have another such flood for 100 years,” would be correct. A 100-year event might happen once, twice, several times, or not at all during our lifetime. Chances are it will only happen once, but there are no guarantees.

Who cares?

It is well known that hydrologic events such as the peak flood flow or the maximum 24-hour rainfall vary from year-to-year in an apparently random and unpredictable fashion. Frequency analysis was developed as a tool to help engineers, hydrologists, watershed managers, and stream ecologists deal with this uncertainty. An engineer or hydrologist would use frequency analysis during the design of dams, bridges, or culverts, where it is necessary to estimate how often storms of a given magnitude will occur. Such estimates allow hydrologists and engineers to design and build the safest possible structures. When designing a 100-year flood spillway for a reservoir estimated to have a 25 year life-span, one might ask, “What is the 100-year flood, what is the probability of exceeding that flood in the next 25 years, and how confident are we in our estimates?" If your house is downstream, you care.

The return period of hydrologic events can be altered by man's activity. This is particularly true on dammed streams or streams whose watershed characteristics have been modified by land use. A prime example being urbanization, which tends to increase flood frequency and severity due to increased storm flow from roofs, streets, etc., as well as reduce base flows due to reduced groundwater recharge. For instance, a peak flow of 20,000 cubic feet per second might have been a 100-year event prior to urbanization, but became a 20-year event following urbanization. Thus, a watershed manager would be interested in examining or estimating potential changes in flow dynamics due to different land uses.

Many stream ecologists believe that both floods and droughts serve as "resetting" mechanisms in stream ecosystems, causing change (succession) in plant and animal populations through time. Thus, the return period of floods and droughts should be of interest to stream ecologists attempting understanding the dynamics of a stream system through time. A fisheries biologist might use frequency analysis to examine the probability that stream flow will be too low to allow passage for migrating fish.

Frequency analysis techniques can be used to assign probabilities and return periods to annual forage production, given sufficient forage production records. One could not predict the exact year in which a drought or bumper grass crop year would occur, but one could estimate the probability of one occurring. This would allow one to assess different enterprises with some sense of the uncertainty or risk due to weather.

Where do these numbers come from?

Hydrologic frequency analysis is conducted using hydrologic records (data sets). Such records are often called *time series*. There are several methods of conducting frequency analysis on a time series to estimate probabilities and return periods. The simplest and most widely used method is called the *graphical* or *plotting position* method. When wishing to conduct frequency analysis at a specific site, one is immediately faced with a problem. Does data exist for the site? The answer is most often no. Methods exist which allow one to use data from upstream or downstream sites, or regional data. Hydrologic models can also be used to generate data for frequency analysis. Extreme care must be taken when using such methods because a lot of assumptions must be made.

An example is the best way to illustrate the estimation of exceedance probability and return period. We will apply graphical frequency analysis to estimate probabilities and return periods for annual peak stream flow—(highest flow each year) on the Scott River at Fort Jones in Siskiyou County, CA. Fortunately, the United State Geological Survey (USGS) has been monitoring stream flow on the Scott River since 1942. Figure 1 is a plot of annual peak stream flow on the Scott River. Figure 1 provides some basic information about peak flow on the Scott River over the last 50 years, such as the maximum and minimum observed flow. We can also get some clue if peak flows are changing over time, either due to land use, stream channel modification, or some other variable. Note that peak flow is highly variable from year-to-year and that no trend (change) seems evident.

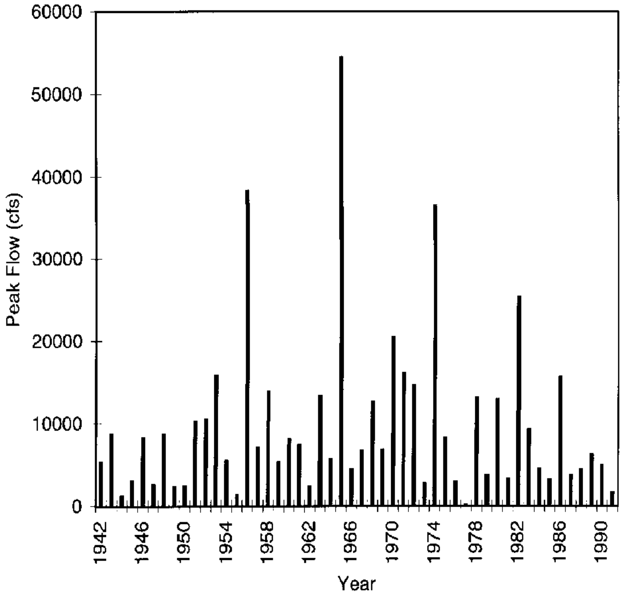

Figure 1

Frequency analysis can only be applied to data sets with no detectable trend in hydrologic response.

Assuming the data set is of adequate length (at least 10 years) and watershed conditions have remained relatively constant, frequency analysis can be used to help us extract valuable information from hydrologic records. The procedure for graphical frequency analysis of annual hydrologic events is simply:
1. rank the data from largest to smallest, 2. calculate the probability of equaling or exceeding each observation as [rank / (total number of observations + 1)], 3. calculate the return period for each observation as [1 / probability of equaling or exceeding], 4. plot the observations with magnitude on the X-axis and probability and return period on the Y-axis, 5. draw (by eye) the "best-fitting" curve through the plots. Again, there are much more complex and exact methods to estimate probability and return period. However, if you encounter an estimate of probability or return period, chances are it was developed using the method described above.
Figures 2 and 3 are plots of exceedance probability and return period developed for the Scott River annual peak flow data illustrated in Figure 1. The triangles represent the probability and return period estimated for each observation following steps 1 through 4. The line represents the "best-fitting" curve drawn by eye. Using Figures 2 and 3 we can estimate an exceedance probability and return period for a given peak flow. For instance, the probability of exceeding a peak flow of 20,000 cubic feet per second (cfs) is approximately 10% (Figure 2). This can also be stated as 90% of annual peak flows will be lower than 20,000 cfs. The return period for a peak flow of 20,000 cfs is approximately 10 years (Figure 3). This can be stated as one would expect annual peak flow to equal or exceed 20,000 cfs once every 10 years. This number provides a starting place for an engineer wishing to design a dam on Scott River capable of withstanding a 10-year flood, or for a stream ecologist wishing to know how often a resetting flood of 20,000 cfs might be expected to occur.

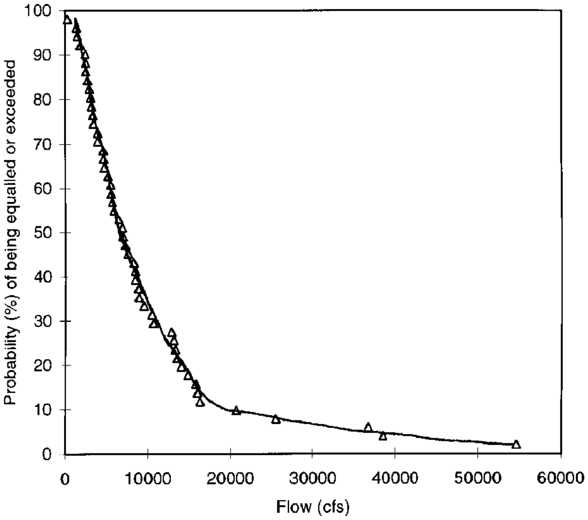

Figure 2

How much confidence can I have in these numbers?

This is the single most important question to be asked and answered. When graphical frequency analysis is used, one should be very skeptical of return period estimates greater than one-fifth the data record length. For Scott River that would be 50 / 5 or 10 years. This rule-of-thumb holds true if we examine Figure 3. Note that 45 of the observed annual peak flows fall below the 10-year return period. Given such a large number of observations, we can have a fair amount of confidence in our estimate of return period for peak flows up to 20,000 cfs. However, the "best-fit" curve estimating return periods from 10 to 50 years was drawn based upon only 5 observations, and mainly upon the maximum observed flow. What if the 50-year event (54,600 cfs) estimated by this 50 year data set is actually the 500-year event? The 500-year flow could be contained in this data set, but we have no way of knowing until we have 500+ years of data.

This brings a very important point to light. We have not estimated the 100-year peak flow for Scott River. The estimates in Figure 3 only go as high as the 50-year event. In order to estimate the 100-year event we must extrapolate beyond the 50 years of data we have. That means we must draw the curve on out to 100 years with no information other than our own judgement and the last few observations, which are already in question. Extrapolation beyond the range of the data should never be done with an eye-fitted curve. Analytical methods of hydrologic frequency analysis must be used to extrapolate beyond the range of data and estimate the 100-year return period peak flow. Even when analytical methods are used, the reality is that we are still estimating the size of the 100-year event from 50 years of data. Data which may or may not include the true 100-year event.

Finally, it should be noted that 50 years of data is the exception, not the rule. Most monitoring stations have a much shorter record. If we are uncomfortable with estimating the 100-year event based upon 50 years of data, how confident will we be estimating it from 15 years of data? So the next time you hear someone confidently stating the size of the 100-year event, ask them: 1. What do these terms mean?, 2. Where do these numbers come from?, and 3. How much confidence can I put in these numbers?