Raster-based Streamflow Analysis -
Hydrologic Regimes As You've Never Seen Before!

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Abstract

A raster-based method of streamflow analysis is presented which allows for the visualization of large datasets and shows subtle temporal properties not possible in more traditional techniques. The method permits numerous plotting options for a variety of uses to show changes to the natural flow regime caused by dam regulation, power production, or other disturbances.

This method can be used as a river management tool to help plan a more natural streamflow regime. Also, the visualization technique is helpful to show changes in streamflow to non-scientific audiences such as the general public, funding organizations, and government/tribal officials.

Background

Streamflow patterns occur on different timescales and show the cumulative effect of watershed disturbances. Such disturbances include both flow volume and timing. Researchers have developed over 170 indices to measure streamflow change. As expected, many of these indices are correlated or redundant.

While such index values are adequate for flow volume (composition), these values are weak when qualifying flow timing (configuration). The raster-based approach helps overcome these limitations when examining the streamflow record.

Application of this method is demonstrated on the US Geological Survey river-gage site on the Colorado River at Lees Ferry, AZ (Figure 1).

The Raster Grid

Using a two-dimensional grid is central to the raster-based approach. When data systematically populate the grid, configuration properties of association, adjacency, distribution, timing, and persistence are measurable and observable quantities. Typical hydrologic indices or statistical measurements best quantify the composition but not the configuration, of daily flows. Patterns that are difficult, or even impossible to identify with linear time-series graphs, are easily recognizable with a raster-based approach.

Figure 2 shows how a linear time-series is transformed into a gridded time-series.

Linear vs. Raster Hydrograph

The traditional linear hydrograph (figure 3) for Lees Ferry, AZ shows general patterns. The peak values before 1962 are related to snowmelt during the spring runoff period. The low value in January 1962 is related to the closing of the Glen Canyon diversion tunnels and the subsequent filling of Lake Powell.

The same dataset is displayed in the raster hydrograph (figure 4). Because individual data points are more clearly distinguished, more patterns are visible. Table 1 lists the common features on both hydrographs.

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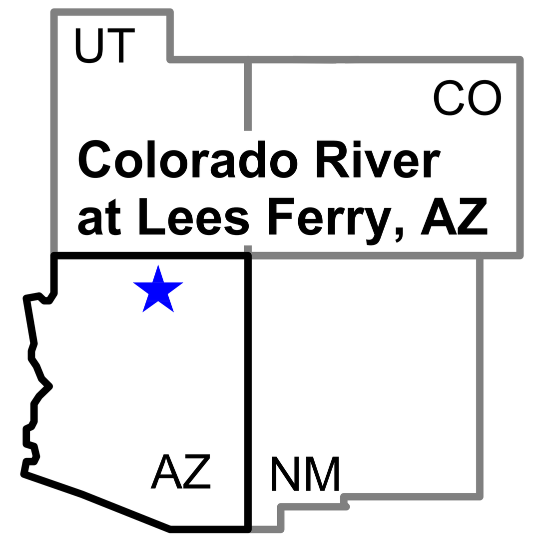

Figure 1. Arizona study site

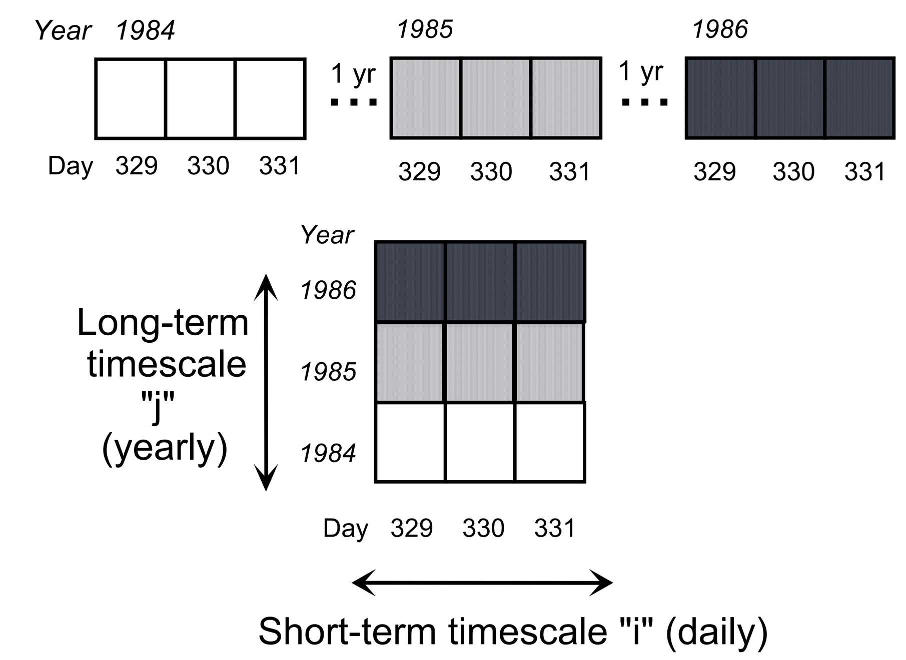

Figure 2. Turning a linear time-series into a gridded time-series

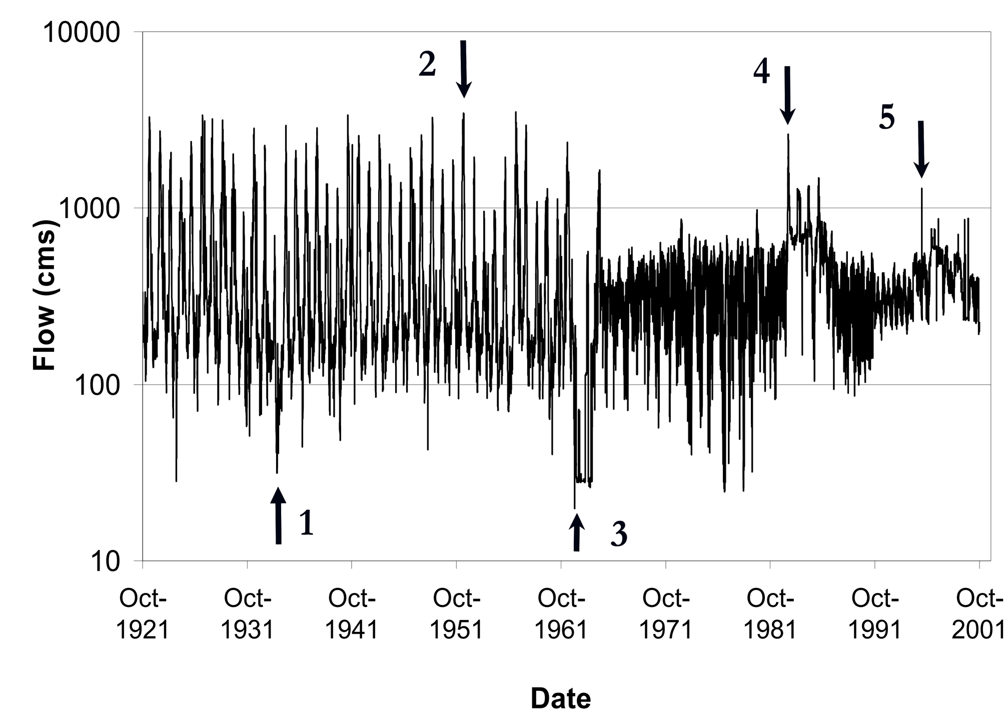

Figure 3. Traditional linear hydrograph

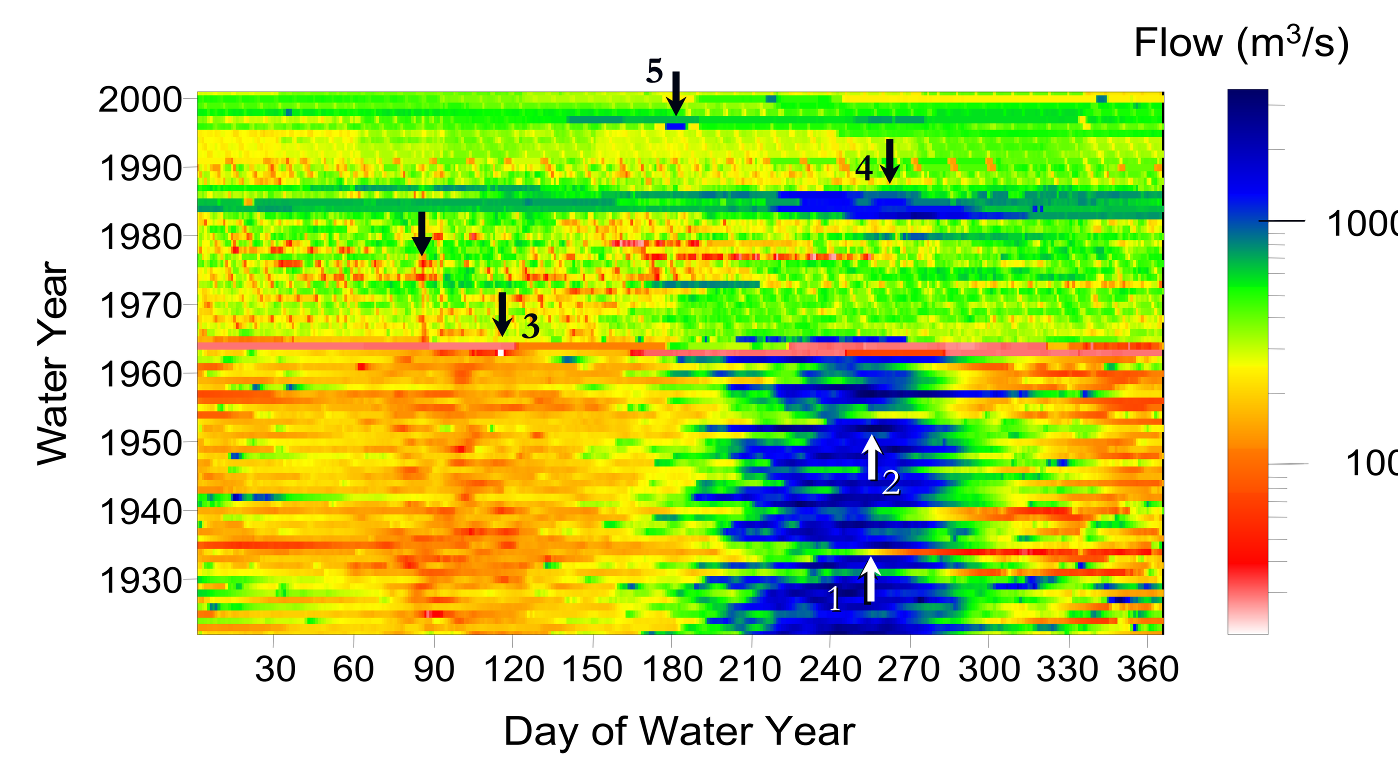

Figure 4. Raster-based hydrograph

TABLE 1. Some flow pattern for Figures 3 and 4

Number	Description
1	Drought
2	Snowmelt peak runoff
3	Glen Canyon Dam closes
4	1983 El Nino high runoff
5	1996 USGS/BOR artificial flood

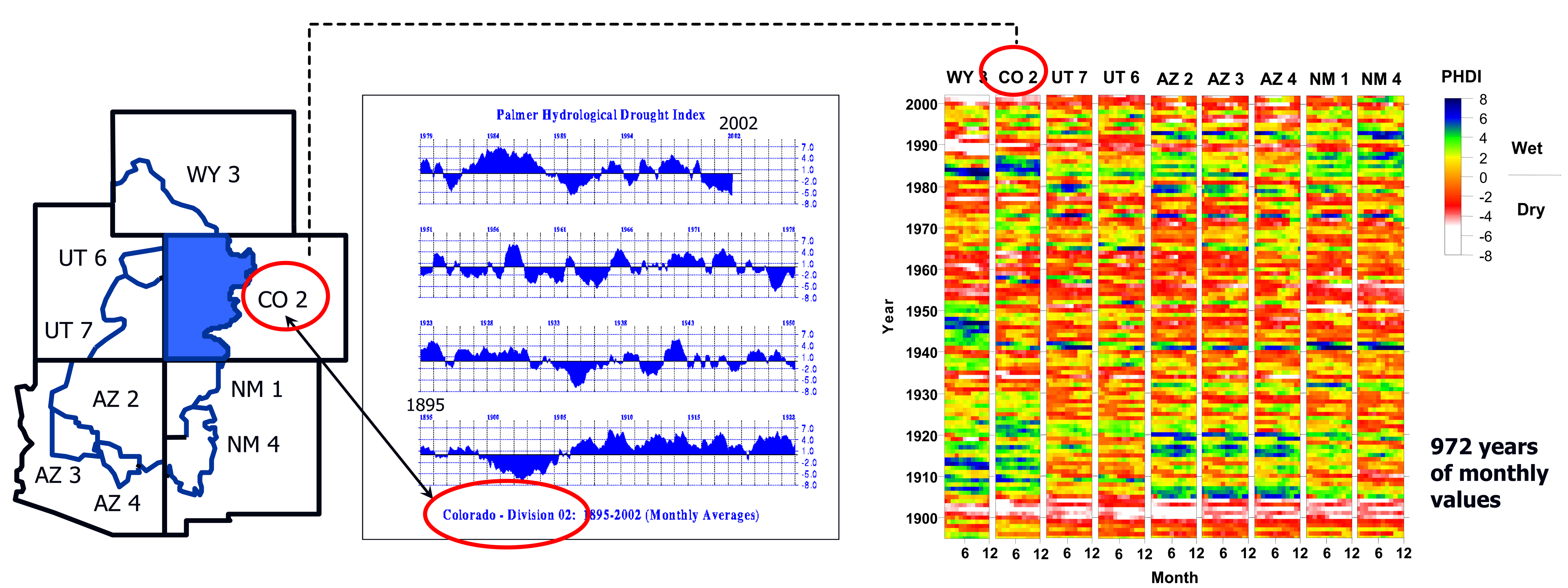

Figure 5. Raster-based method applied to climate graphs

Natural Flow Analysis

To reproduce natural flow-patterns, targeted discharge must replicate the time-based variability within and between years. New tools are needed, such as the dual-timescale raster-hydrograph to show daily and yearly flow composition and configuration variability simultaneously.

The resulting pattern of patches for different flows at different times of the year is central to characterizing, understanding, and replicating the natural temporal variability of a river.

The raster-based methodology allows for the identification, quantification, and visualization of streamflow variations across daily, monthly, seasonal, yearly, and decadal time-scales using pattern analysis developed for landscape ecology.

River restoration application

The raster-based method is well suited to address many concerns expressed by natural-resource managers and researchers. A patch-work or □management mosaic□of flow-categories would incorporate the multi-year daily, seasonal, and annual variations not possible with minimum-flow requirements or targeted monthly flows.

Different flow regimes for wet years and dry years can be accommodated by different □management-mosaic□scenarios. In all cases, the natural variability of a stream would be included, an element lacking in current management techniques.

Application to other time-series

Another possible use for the raster-based method is with other time-series data. Within the water resources community, understanding past climatic trends is an important factor.

One commonly used climate factor is the Palmer Hydrologic Drought Index (PHDI). The index was developed during the early 1960's by W. C. Palmer as one way to quantify the severity of hydrologic drought conditions. The federal government and many state governments rely on Palmer index values to trigger drought-relief programs.

Figure 5a shows the location of state climate zones of the surface water production areas of the Colorado River watershed. Figure 5b is the traditional way to show a PHDI for a single climate region, in this case western Colorado.

With a raster-based approach, both temporal and spatial distribution of drought conditions during a period of 108 years for the entire Colorado River watershed can be viewed (figure 5c). A total of 972 record years of monthly data are displayed.

Summary

The raster-based analysis and visualization methodology is an innovative and highly illustrative approach to examine large time-series datasets. Raster-based hydrographs and patch-analysis are new visualization tools that are well suited for hydrology and water resource management.