

## 2A.8

### THE SPRING RUNOFF PULSE FROM THE SIERRA NEVADA

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#### Introduction

A spring runoff pulse that makes the transition from low streamflow conditions in winter to the high streamflow conditions in the later spring-early summer period is identified in the Merced River record from the Sierra Nevada. The timing of the pulse is delayed with greater seasonal accumulation of snow pack in the Yosemite region. Also, the runoff pulse is triggered by a regional weather fluctuation that establishes a warm high pressure ridge over the California region during the spring (mid-March to mid-May) period. This ridge often blankets the entire western United States, and it is found that a simultaneous pulse occurs over a broad collection of high-elevation streams in the region.

#### 1. Introduction

Snowmelt runoff from the Sierra Nevada constitutes a large component of the California water supply and contributes greatly to the freshwater budget associated with the San Francisco Bay system. Just about every year there is one pulse of snowmelt runoff (streamflow) that marks the transition of the Sierra climate from winter to spring. Three examples during the early 1980's from Merced River hydrographs show a very late spring pulse (1983), a very early spring pulse (1985), and a fairly average time of the spring pulse (1980).

The record of daily flows (1948 - 1996) at Happy Isles in Yosemite National Park provides a convenient history from which we identified the spring pulse. On average, the pulse at Happy Isles occurs in mid-April, but it varies considerably — as early as mid-March and as late as mid-May. Also superimposed on the spring rise in streamflow are several day-long peaks and troughs in the streamflow that are the subject of companion studies aimed at modeling (Peterson et al., 1998) and prediction (Dettinger, et al., 1998).

The marked increase in the flow over what would be expected from climatological spring conditions is the composite streamflow of the Merced Happy Isles record corresponding to its spring pulse period, from the initial day through 19 days later. The composite is constructed from averaging 43 cases of Happy Isles Merced River pulse episodes. In comparison is shown the climatological mean Merced streamflow over the same 43 years, but for the fixed period of April 19 to May 6 which is centered during the overall average period of the spring pulse. A one tailed t-test indicates that the rise in streamflow during the pulse period is greater than climatological streamflow at a high level of confidence (95% confidence). It is not uncommon for the flow to increase three- or four-fold over the 20 days after the pulse begins; the flow during the pulse period reaches values twice that expected by climatology.

But what causes it, and why is it so sudden?

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## 2. Two Influences: Seasonal snow accumulation and Spring synoptic weather patterns

To get at the origin of the spring runoff pulses, we examined the history of the pulse times over the 48-year Happy Isles record (1948-1995) in Yosemite National Park in association with various climate and weather conditions.

First, the Merced River Happy Isles record shows that the pulse comes earlier in years with low discharge (light snowpack) and later in years with high discharge (heavy snowpack). This may result from two effects: (1) the heavier the total annual flow, the more likely that there is a long winter; and (2) the greater the snowpack, the longer the period of heating that is required to bring it to the melting state. Interestingly, the record shows a subtle trend toward the pulse occurring earlier, amounting to an advance of about 7 days over the 46 years since 1948. Studies by Roos (1987, 1991) and Wahl (1992) have documented this trend; Aguado et al. (1992) and Dettinger and Cayan (1995) have shown that the trend is from multiple factors but especially from warmer winters yielding earlier runoff in the Sierras. Dettinger and Cayan (1995) show that this trend is most pronounced in middle elevation snow-fed catchments, noting that the high elevation Merced basin contains some of this signal. Also, while there is not a useful link to El Niño years, there is a suggestion that the springs following the mature phase La Niña events tend to have the pulse delayed from the climatological timing.

However, there is also a synoptic weather influence. Given the time of the pulse for each year, we composited (averaged) the 700-mb height anomalies and daily maximum temperature over a sequence from 5-days-before through 5-days-after the initial day of the pulse. For brevity, we will show the 700 mb height and maximum temperature anomalies only for the third day after the onset of the pulse. The 700-mb height is a good measure of atmospheric circulation (speed and direction of the winds, about 3 km above sea level) and provides a history that covers the period since World War II. The composite sequence of 700-mb height anomaly maps clearly show that in many cases, the pulse is triggered by an orderly atmospheric pattern: a cool, wet period with a trough (negative 700-mb height anomalies) along the West Coast preceding the spring pulse moves

through, and is succeeded by the development of a strong ridge of high pressure (positive 700-mb height anomalies) that blankets the western United States. This high pressure ridge produces warm air and probably makes cloud-free skies—elements conducive to melting the winter snowpack. The companion set of maps of composite daily maximum temperature anomalies reinforce the picture of a cool pattern over the West evolving into a warm pattern. Average daily maximum temperatures are approximately 3 deg C above the long-term average in Northern California.

## 3. The spring pulse as a Western U.S. phenomenon

Because the atmospheric pattern that drives the runoff pulse covers a broad region, could it be that the Happy Isles record provides an index of spring high elevation snowmelt over a much broader region?

An important feature of the 700-mb circulation and temperature anomaly maps described above, is that they cover a large region, much broader than the Merced River basin, or indeed the entire Sierra Nevada. Using the Happy Isles Spring pulse record, a large set of 344 streamflow records from the USGS streamflow HCDN historical climate set (Slack and Landwehr, 1992) was interrogated. After investigating the daily hydrographs from a variety of regions, we considered an index designed to measure the behavior of the western streams in association with the Happy Isles pulse from its inception to its completion. An initial investigation of the ensemble of spring hydrographs for other selected streams (not shown) indicates that other high elevation watersheds in the Rocky Mountains are surging above climatological levels at the same time as the Merced River spring pulse.

## 4. Conclusions

High elevation Sierra runoff, as indicated by the Merced River Happy Isles stream gage record in Yosemite National Park, usually undergoes a pulse of high flow in spring that marks the transition from low winter flow to high spring/early summer flow. This pulse has considerably larger flows than would be expected from the increase in climatological

mean flow in spring, and it usually has a much sharper rise. Because of this abrupt onset of the spring pulse, it would be very valuable to understand and predict the character of the pulse in a given year. Both seasonal snow accumulation (late fall through spring), and spring atmospheric circulation play an important role in the timing of the spring pulse. Usually, a larger accumulated snowpack produces a later spring pulse. The spring weather pattern that triggers the pulse features a strong western high pressure ridge; this atmospheric forcing produces widespread warming presumably because of strong solar heating of the snowpack. Importantly, there is an overall coherent pattern of spring pulse over the high elevation watersheds in the West. Inspection of the western U.S. stream gage dataset indicates that the Happy Isles record provides an index of the spring pulse over a much broader region of the high elevations including the Sierras and the Rocky Mountains. Thus, the Merced Happy Isles gage provides a convenient index of a widespread western U.S. spring runoff pulse, although it may not be the optimum such index. Work to better elucidate this pattern, and to identify coherent schemes for predicting the spring pulse, is underway by USGS researchers, along with collaborations with Scripps Institution of Oceanography, NOAA Climate Diagnostics Center, and NASA Goddard Space Flight Center.

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