EXECUTIVE SUMMARY

This report analyzes long-term (1953-2014 in most cases, but some analyses span back as far as 1910) trends in streamflow and precipitation in the Eel River Basin, located on California's North Coast. I evaluated trends in streamflow and precipitation-adjusted streamflow separately for each of the 365 days of the year, providing greater temporal detail than a previous analysis (Asarian and Walker *in press*) that used similar methods but a monthly time step.

I obtained daily streamflow data for ten long-term stream gages from the U.S. Geological Survey. The mainstem and South Fork of the Eel River have multiple streamflow gages, allowing for the calculation (i.e., downstream flow minus upstream flow) of "accretions" between gages, which represents the net contributions of all tributaries, springs, and groundwater, minus any diversions. I combined data from several nearby precipitation stations to calculate a time series of Antecedent Precipitation Index (API) for the watershed contributing to each streamflow site. API is a time-weighted summary of precipitation which provides high weight to recent precipitation and low weight to precipitation that occurred many months ago. I used a regression model of the relationship between API and streamflow to calculate "precipitation-adjusted streamflow", which statistically reduced the year-to-year fluctuations caused by variable precipitation and allowed evaluation of the underlying streamflow trend.

For the five long-term benchmark precipitation stations closest to the Eel River Basin (there are none within the Basin), there were no statistically significant trends in annual total precipitation for 1880-2014 or any shorter period ending in 2014; however, decadal and multi-decadal cycles are evident. Monthly trends included decreased January precipitation since the mid-20th century at all five stations and increased March precipitation since the early 20th century at Orleans, Eureka, and Fort Bragg. Only one benchmark station (Weaverville) had decreasing September precipitation for 1953-2014, contrary to a previous analysis (Asarian and Walker *in press*) which found geographically widespread declines in September precipitation for 1953-2012.

I characterized trends by both their duration (i.e., the number of days with a statistically significant decreasing or increasing trend) and their magnitude (i.e., slope, the amount of change that occurred across the 1953-2014 trend period). For each day of the year, I express magnitude in three ways:
1) absolute trend magnitude (i.e., annual slope of the trend) in units of cubic feet per second per year,
2) relative trend magnitude (i.e., annual slope of the trend relative to 1953-2014 median flow) in units of percent per year, and
3) trend magnitude normalized to watershed area (i.e., absolute trend magnitude divided by watershed area) in units of cubic meters per day per square kilometer of watershed area.

Both streamflow and precipitation-adjusted streamflow declined at most tributary sites in the Eel River Basin during the low-flow season over the 1953-2014 period, especially from July through mid-October when streamflows are lowest. At most tributary sites, the number of days of the year with a declining trend was higher for precipitation-adjusted streamflow than streamflow (Figure ES-1), likely because accounting for precipitation reduces inter-annual fluctuations that can impair statistical detection of streamflow trends. The relative magnitude of declines (i.e., the slope of the trend) was higher for streamflow than for precipitation-adjusted streamflow, indicating that precipitation patterns are contributing to streamflow declines (i.e., dry years are more frequent in recent years than in the early decades of the 1953-2014 trend period).

The number of days of the year with a declining streamflow trend for the 1953-2014 period varied among tributary sites (Figure ES-1), with the fewest number of days at Elder Creek, Middle Fork Eel River, and accretions between Fort Seward and Scotia, followed by the South Fork Eel at Leggett. The relative magnitude (i.e., annual trend slope as a percent of 1953-2014 median flow) of declining trends were steepest (up to 6% per year for late August and September) for accretions to the mainstem Eel River from Van Arsdale to Fort Seward, but when normalized to watershed area (i.e., absolute trend magnitude divided by watershed area) the declines were actually among the least steep. The relative magnitude of declining trends were also steep (greater than 2% per year for late August and September) at Bull Creek and accretions to the South Fork Eel between Leggett and Miranda. The relative magnitude of declines at the Van Duzen River and the combined accretions from Van Arsdale to Scotia (includes the entire South, Middle, and North forks of the Eel River) were ~1% in August through mid-October; compared to Bull Creek and accretions to the South Fork Eel between Leggett and Miranda, the relative magnitude of declines is lower but the numbers of days with declines is similar.

Trends in streamflow and precipitation-adjusted streamflow at mainstem Eel River stations for the 1953-2014 period show a clear upstream/downstream pattern, with large increases directly below Van Arsdale Dam (2-15% per year during April through December), almost no trends at Fort Seward (the next mainstem gage) as decreased contributions from the tributaries and/or increased diversions from the mainstem offset increased Van Arsdale releases, and then declines at Scotia (the furthest downstream gage) of similar magnitude/duration as those of the tributaries (Figure ES-1).

With the exception of precipitation quantity, the methods used in this analysis do not allow individual quantification of the factors contributing to streamflow declines. However, the long-term streamflow gages include a diverse range of watershed and climate conditions. Thus, we can hypothesize about causal mechanisms by carefully examining the trends that have occurred in watersheds with different conditions/histories. Potential factors include increased water diversions and/or increased evapotranspiration by vegetation/forests. Increased evapotranspiration could be due to climate (i.e., air temperature, wind, humidity, or precipitation shifting from snow to rain) and/or structure/composition of vegetation.

Elder Creek is one of the most pristine watersheds within the Eel River Basin, with almost no diversions, roads, or history of timber harvest. Elder Creek had declining trends in streamflow but not precipitation-adjusted streamflow. In other words, Elder Creek maintained its relationship between precipitation and streamflow through the 1953-2014 period, in contrast to most other sites where the relationship diverged. This suggests that streamflow decreases at other sites are more likely the result of increased water withdrawals and/or vegetation structure/composition changes than other (i.e., aside from precipitation quantity) climate factors. As the planet continues to warm, even pristine watersheds like Elder Creek will likely experience streamflow declines due to the increased evapotranspiration resulting from increased temperatures.

This study did not quantify water diversions but precipitation-adjusted streamflow trends from the previous analysis (Asarian and Walker *in press*), and to a lesser extent this study[1], suggest that diversions are an important factor influencing summer streamflow declines. California Department of Fish and Wildlife estimates for marijuana-related water use within five Northwest California watersheds

[1]There are only two stream gages not affected by diversions, so the sample size is small.

range from approximately 1 to 10 cubic meters of water per day per square kilometer of watershed area. In comparison, the total magnitude of the decline in precipitation-adjusted streamflows across the entire 62 year period 1953-2014 (i.e., annual trend magnitude multiplied by 62 years) during the months of July-October in this study was in the range of 30 to 100 cubic meters of water per day per square kilometer of watershed area for most tributary sites, indicating that water diversions for marijuana cultivation likely explain only a relatively small fraction (i.e., roughly 1% to 33%) of the total declines. These results do not mean that water diversions for marijuana cultivation do not have serious, even catastrophic, effects on streamflows in many Eel River Basin streams, including those with the highest value salmonid habitats, it just means that these diversions are only a partial explanation for basin-scale declines in streamflow. Despite being responsible for only a portion of streamflow declines, recent increases in diversions are a key additional impact compounding with previous impacts. Furthermore, diversions are perhaps the only factor causing streamflow declines that could actually be substantively addressed in the near-term (i.e., water can be stored in tanks and ponds when it is abundant during winter and early spring, offsetting the need for summer diversions).

Because evapotranspiration is such a large portion of the annual water budget, small changes in evapotranspiration have the potential for large effects on summer streamflows. The Eel River Basin's forests have undergone substantial changes in the past century as a result of timber harvest and fire suppression. Without fire or mechanical intervention, Douglas-fir trees are invading prairies and oak woodlands, potentially increasing evapotranspiration. The young dense forests of the Eel River Basin may be in a state of maximum evapotranspiration. Bull Creek provides evidence supporting the hypothesis that vegetation change is contributing to streamflow declines, because despite lacking water diversions it had the largest number of days (and nearly the greatest magnitude of declines) with declining precipitation-adjusted streamflow (Figure ES-1), coinciding with the regeneration of its forests following intensive logging that occurred prior to installation of the stream gage in 1960.

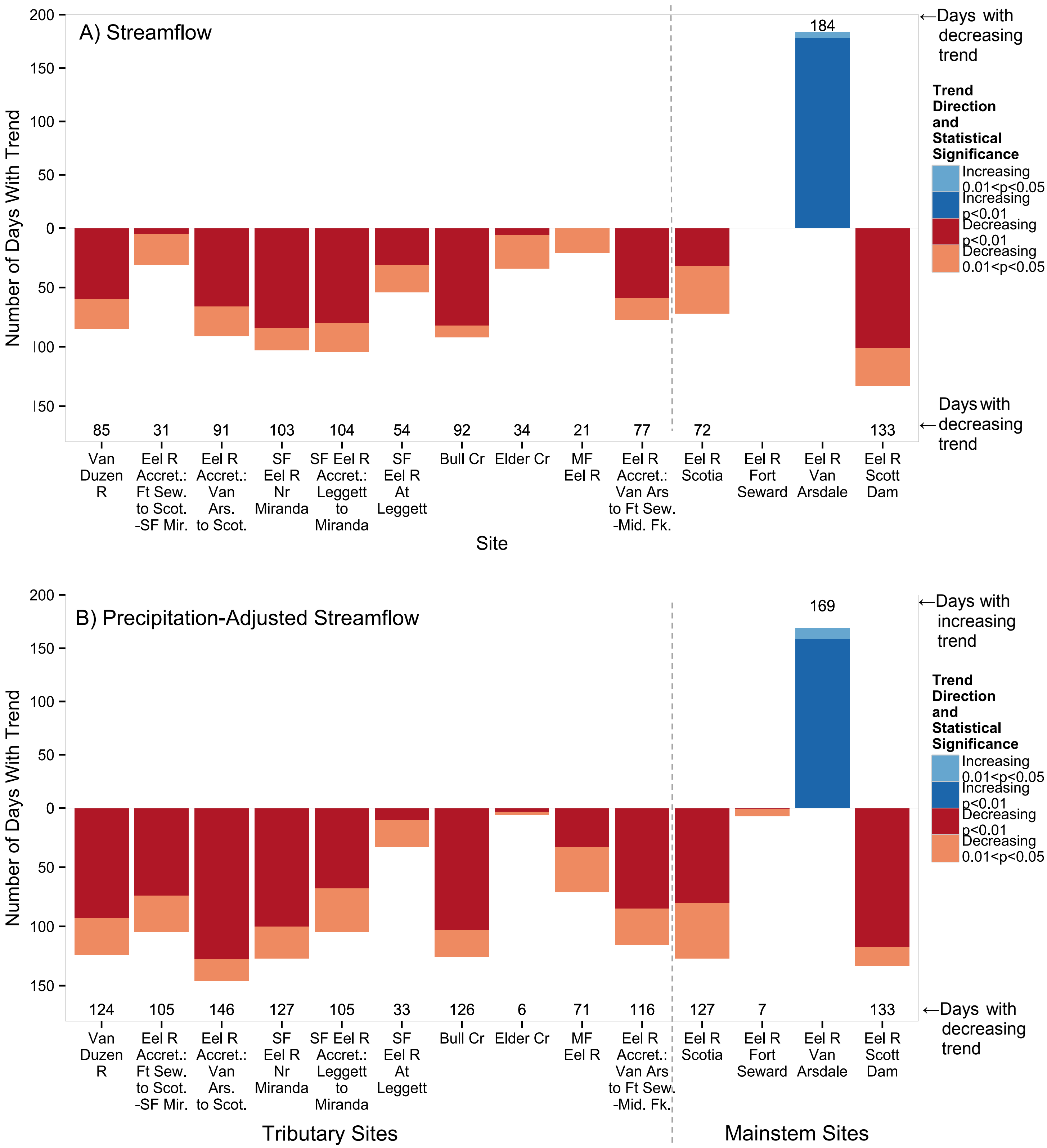

Figure ES-1. The number of days in May through October (184 possible days) with increasing or decreasing trends in (A) streamflow and (B) precipitation-adjusted streamflow at mainstem and tributary sites for WY1953-2014. Bars are stacked with colors indicating statistical significance and labels indicating the total number of days with an increasing or decreasing trend.