Dennis Jackson - Hydrologist

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November 5, 2009

Tom Lippe
329 Bryant Street, Suite 3D
San Francisco, CA 94107

Re: Negative Declaration for Tezt-P08·00565·ECPA

Dear Mr. Lippe:

You have asked me to comment on the potential impacts of the proposed Tezt Vineyard conversion from oak woodland and grassland to vineyard. The project is located at: 916 Sanitarium Road, Deer Park, CA 94576. The property consists of two parcels totaling 19 acres. An Initial Study (IS) and Negative Declaration (ND) was prepared, dated October 8, 2009.

The project under consideration is an effort by the property owner and Napa County to reduce the environmental impacts of a vineyard that was installed without County approval or Erosion Control Plan. The vineyard appears to have been incrementally installed between 1993 and 2009 (Table 1 of the IS/ND).

The ND gives the following description of the project.

> *The project proposes implementation and maintenance of temporary and permanent erosion control measures within approximately 7.9 acres (6.4 net acres) of an existing 10 acre vineyard planted without the benefit of a County approved erosion control plan permit. Approximately 2.1 acres of existing vineyard within portions of Blocks A, B, D and E, including 0.30 acres on slopes exceeding 30% shall be removed and the disturbed areas restored using native vegetation (refer to Section IV, Biological Resources). The project also proposes the removal of vineyards and restoration of an 800 linear foot reach of an unnamed blue-lined stream, in accordance with the Tezt Vineyard Development Restoration Plan, prepared by Phil Blake of the Natural Resource Conservation District, dated May 2009 (referenced herein, available for review at the Napa County Conservation, Development & Planning Department). The project proposed to retain 7.9 gross acres of vineyard (6.4 net acres) following implementation of the proposed restoration plan. The vineyard has been planted on slopes that range from 12% to 31%, with approximately 0.14 acres occurring on slopes over 30%. Existing deer exclusion fencing is located along the eastern property boundary adjacent to Blocks A, C, H, and I, and along the western property boundary adjacent to Blocks E and G. The remainder of the property is bound by residential development and vineyard to the south, and to the north oak woodland and a single unnamed blue-line stream flowing in an east - west direction north of the existing vineyard that drains to Bell Creek south of Bell Canyon Reservoir.*
>
> Erosion Control Measures: Temporary erosion control measures include, fiber rolls, straw bale dikes across the vineyard avenues between Blocks A and C, and straw mulch. Straw mulch would be applied on all disturbed areas and exposed soil in traffic areas to control erosion and dust at a rate of 2,000 pounds (lbs) per acre. Permanent measures include a permanent no-till cover crop with a minimum of 70-

> 75% coverage in addition to existing permanent erosion control features. Maintenance of existing features would include reshaping waterbars, placement of rock slope protection within the existing ditches through Blocks F and G, and maintenance of all existing roadside ditches, diversion ditches, drop inlets and culverts.

The Initial Study/Negative Declaration (IS/ND) goes on to state that:

> *The vineyard development was completed between 2007 and 2009; however, for the purposes of this analysis, aerial photographs provided by the project engineer were provided to determine baseline conditions prior to vineyard development.*

The baseline for the environmental assessment is the conditions prior to the installation of the unpermitted vineyard. Table 1 of the IS/ND shows that the vineyard development began some time in 1993 or 1994. The restoration of the blue-lined stream exemplifies the commitment to assess the environmental impacts of the proposed project against the conditions prior to the installation of the unpermitted vineyard. However, this same standard does not appear to have been applied to other portions of the unpermitted vineyard.

Incomplete Project Description

The baseline for the environmental assessment of the Tezt Vineyard Conversion is the conditions prior to the installation of the 10-acre unpermitted vineyard. Therefore, the project description must include not only the restoration plan for the blue-line creek and the erosion control plan but also other features of the unpermitted vineyard.

The unpermitted vineyard included installation of diversion ditches and subsurface drains. These drains increase the speed of stormwater runoff leaving the site. The environmental impact of these drainage ways was not discussed or assessed by the IS/ND. The discussion of the TR-55 model in the section on Hydrology and Water Quality did not mention these drainage ways and so their effect was likely not included when estimating the runoff discharge from the unpermitted vineyard.

The unpermitted vineyard also includes a settlement pond. The IS/ND does not assess the environmental impact of the settling pond and does not investigate if the pond is properly sized. The IS/ND does not discuss where the settling pond drains to or if the course of the natural drainage was altered.

The IS/ND does not mention that the Napa River is impaired for sediment. Recognizing that the Napa River is impaired for sediment is crucial to the environmental assessment process for any project that has the potential to increase the water or sediment discharge from the project area.

The project description does not describe the project well or note the distances from the project well to neighboring wells. The IS/ND relies on a Phase I Water Availability Analysis to determine if there is any adverse impact to the groundwater resource. However, the County's Water Availability Analysis has never been subjected to a California Environmental Quality review so there is no evidence that the County's procedure adequately protects the groundwater resource.

The project description in the IS/ND states that water will be provided by an existing well. However, the notes on page 1 of the ECP state that:

> The parcels include ±8.2 net acres of existing vineyard (1.8 acres to be removed) associated vineyard avenues, access roads, three residences and ±8 acres of tree canopy, brush and resident grasses. Main access is from Sanitarium Road. The only change to the existing vineyard will be modification of the vineyard footprint due to vineyard removal. The existing ground slopes in the project area range from 12% to 31% with the slopes over 30% being confined to 0.14 acres within Block F. The water source for the vineyard is an ***existing well and existing spring***. Water use on the vineyard after restoration is expected to be ±2.1 afa (acre feet per annum) which includes potential use of water for frost protection. The frost protection system consists of misters with a rate of 1:20 gpm per acre. Assuming a maximum of 30 hours per year, frost protection use is estimated to be 0.7 afa. Maximum water use on the parcel for all purposes

> is expected to be ±5 afa; 1.5 afa of this is delivered for domestic use by the hospital water system. (Emphasis added)

The discussion in Section IV, Biological Resources, does not mention a spring on the property. Where is this spring located? How is the spring being tapped for irrigation of the vineyard? Are there any biological impacts from using the spring for irrigation?

The "small shed" used to store hazardous chemicals is 700 feet from the blue-line stream but it appears to be within 100 feet of drainage channel in Block G. This appears to be a violation of the Napa County Conservation Regulations.

The details of the soil loss calculations were not included in the IS/ND so I cannot assess if they are reasonable.

Incomplete Project Environmental Analysis

The *Hydrology and Water Quality* discussion in the IS/ND (Section VIII of the Environmental Checklist) does not mention that the Napa River has been declared impaired by the San Francisco Bay Regional Water Quality Control Board (SFBRWQCB) due to a high sediment load. The SFBRWQCB has been working to prepare a Total Daily Maximum Load plan (TMDL) to reduce the volume of sediment carried by the Napa River.

The *Napa River Basin Limiting Factors Analysis* (Stillwater Sciences and Dietrich, 2002) report, prepared as part of the TMDL process, found that two adverse impacts of erosion and sedimentation on salmon and steelhead habitat:

- Low permeability values indicating a high concentration of fine sediment in the streambed,
- Channel incision in mainstem Napa River

The environmental analysis in the IS/ND does not discuss how the Tezt Vineyard Conversion project has the potential to change the composition of the sediment delivered to the Napa River system. Shifting the mean diameter of the sediment produced on the Tezt parcel to a finer caliber would potentially decrease the permeability of streambed gravel beds which would adversely impact salmon and steelhead habitat. This is especially important since salmon and steelhead are listed species. Typically, sediment control measures are good at capturing coarse sediment but often do not capture all of the finer sediment.

The environmental analysis presented in the IS/ND also does not examine the Tezt Vineyard Conversion projects potential to contribute to channel incision in the Napa River. The discussion of parts (c) and (d) of the *Hydrology and Water Quality* (Section VIII Environmental Checklist) states that:

> The project does not propose the alteration of this stream in a manner that would result in increased on- or offsite flooding. Based on erosion control plan #POB-00565 and measures proposed within this document, implementation of the proposed project would not result in increased soil loss and runoff, and would improve soil stability by implementing a permanent cover crop maintaining 70-75% or greater coverage (Figure 2). Proposed temporary erosion control measures include, but are not limited to fiber rolls, straw bale dikes across the vineyard avenues between Blocks A and C, and straw mulch. Straw mulch would be applied on all disturbed areas and exposed soil in traffic areas to control erosion and dust at a rate of 2,000 pounds (lbs) per acre. Permanent measures include a permanent no-till cover crop, maintenance of existing features, including reshaping waterbars, placement of rock slope protection within the existing ditches through Blocks F and G, and maintenance of all existing roadside ditches, diversion ditches, drop inlets and culverts. Implementation of the proposed project and restoration plan would not result in increased sedimentation and/or increases in runoff contributing to on- or off-site flooding. However, to ensure the long-term efficiency of proposed erosion control features and structures, proper function is dependent upon soil stability, structure and depth, the vegetative cover type, and an adequate maintenance regime. As mentioned, there is one watercourse within the project site. This watercourse drains southwest towards Bell Creek, located south of Bell Canyon Reservoir. The project does not propose any alternations to the course of a stream or river that would result in ***substantial erosion or***

> ***siltation*** nor would the project contribute substantially to off-site flooding. Therefore, this project would not result in a significant impact. (Emphasis added)

The fact that the IS/ND does not mention that the Napa River is impaired for sediment brings into question the appropriateness of the test for significance applied by the IS/ND. Given that the Napa River is impaired for sediment and supports listed fish it is inappropriate for the IS/ND to require that the project cause “substantial erosion or siltation” before the impacts from the project are considered significant.

I do not have the details of how the TR-55 model was applied to the Tezt Vineyard Conversion so I can not ascertain if the model output is reasonable. For example, there is no indication that the TR-55 model was setup to account for the surface drainage ditches and subsurface drainage pipes in the vineyard blocks for the post-project modeling exercise. These features would shorten the sheet flow distance and the shallow concentrated flow distance while increasing the length of channel. The net result would be to speed the runoff from the vineyard area compared to pre-project conditions.

The TR-55 model prepared for the Tezt Vineyard Conversion only looked at maximum discharge rates and did not examine if changes in total storm runoff volume would occur. The sediment impairment of the Napa River is sensitive to increases in either peak storm discharge or increases in total storm discharge volume. I present evidence below demonstrating that there has been an increase in the duration of high flows in the Napa River.

The TR-55 model does not account for subsurface storm-flow. In my opinion, the Tezt Vineyard conversion project will increase not only surface storm-flow but also subsurface storm-flow. The combined increase in both surface and subsurface storm-flow from the Tezt Vineyard Conversion will result in a cumulative impact that sustains high flows in the Napa River. Sustained high flows in the Napa River erode the bed and banks of the river and result in channel incision (the progressive lowering of the stream channel).

To assess the impact of the change in storm-flow discharge from the Tezt Vineyard Conversion requires that all development projects that affect the storm discharge in the Napa River be considered. I present evidence of a statistically significant change in storm discharge in the Napa River to demonstrate that the cumulative impact of development projects on the discharge in the Napa River is already occurring. The change in storm-flow that I present is linked to the channel incision process which Stillwater and Dietrich (2002) demonstrate has a significant adverse impact on salmon and steelhead habitat.

Statistical Evidence Change in Napa River Discharge

The following is a summary of a statistical analysis of the discharge of the Napa River. Details of the statistical analysis are attached as an appendix to this letter.

The U.S. Geological Survey (USGS) maintains two stream gaging stations on the Napa River. One station is located near Zinfandel Lane and is called the Napa River near St Helena. The drainage area above this station is 88.1 square-miles. The other station is at Oak Knoll Avenue and is called the Napa River near Napa. Its drainage area is 218 square-miles and includes the watershed above Lake Hennessey.

Changes in land use have been occurring in the Napa River watershed over the last two hundred years approximately. I assumed that the latest changes began in the mid 1970’s with the expansion of vineyards. Therefore, I divided the discharge record into the pre-expansion period of 1930-1975 and to the expansion period of 1976-2006. However, the discharge record at both stations has record for only 1930-1932. Data collection was resumed in 1940 at the St Helena station and in 1960 at the Napa River near Napa gage.

There is a weather station at Angwin. The 3-day total rainfall at Angwin on the day of the annual maximum discharge at the Napa River near Napa showed no statistical difference in either the variance or the mean for the periods 1960-1975 and 1976-2007. Rainfall data at Angwin was not available in the early 1930’s. These tests show that the changes in the storm discharge between 1960-1975 and 1976-2006 were not the result of changes in rainfall.

Changes in land use can cause a change in either the mean or variance of stream discharge data (McCuen, 2003). An increase in discharge variance indicates an increase in variability of the discharge data. An increase in the discharge variance means that either the low flows are getting lower or the high flows are getting higher or that both are becoming more extreme.

Table 1 summarizes the changes in the distribution of storm discharges. Table 2 summarizes the statistical tests on the Angwin 3-day rainfall. All statistical tests were done using alpha set at 0.05 which means there is only a 5% chance that the changes deemed significant are the result of chance.

No significant difference was found in either the mean or the variance of the annual maximum discharge for the Napa River near St Helena. This analysis found a significant increase in the variance of the associated daily discharge of the Napa River near St Helena. No significant difference was found in the mean of the associated daily discharge at the Napa River near St Helena.

A significant increase was found in the variance of both the annual maximum discharge and the associated daily discharge for the Napa River near Napa. But no difference was found in the mean of either the annual maximum or the associated daily discharge.

No difference in the variance of either the ratio (upstream discharge divided by downstream discharge) of the annual maximum or ratio of the associated daily discharge was found. A statistically significant increase in the mean of the ratio of the annual-maximum-discharge at the Napa-River-near-Napa to the Napa-River-near-St-Helena was found (alpha = 0.05). And a statistically significant increase in the mean of the ratio of the associated-daily-discharge at the Napa-River-near-Napa to the Napa-River-near-St-Helena was found (alpha = 0.05).

The statistically significant increase in the two ratios indicate that the watershed between the two gaging stations is contributing significantly more discharge during the 1976-2006 period than was contributed during the 1930-1975 period. This increase in discharge in the downstream direction between the two time periods indicates that the Napa River has more power to erode the bed and banks of the river which has been found to adversely impact salmon and steelhead habitat.

Since there was no change in rainfall during the two time periods it is reasonable to conclude that the changes in land use during the 1976-2006 time period are generating more surface and subsurface storm water runoff. The predominate change of land use in the 1976-2006 time period has been the increase in vineyard acreage, especially hillside vineyards.

Table 1. Summary of Changes in Discharge. The variance and the mean for the annual maximum discharge and the associated daily average discharge were compared for the periods 1930-1975 and 1976-2006 for two USGS gaging stations on the Napa River. The mean and variance for the ratio between the downstream-station and the upstream-station were also compared for the periods 1930-1975 and 1976-2006. All the tests used an alpha of 0.05.

Streamflow	Parameter	Napa near St Helena	Napa near Napa	Ratio Napa to St Helena
Annual Maximum Discharge	variance	equal	**Significant Increase**	equal
	mean	no difference	no difference	**Significant Increase**
Associated Daily Discharge	variance	**Significant Increase**	**Significant Increase**	equal
	mean	no difference	no difference	**Significant Increase**

Table 2. Summary of Rainfall. No statistical difference in Angwin 3-Day rainfall on the day of the annual maximum discharge at the Napa River near Napa.

Angwin 3-Day Rainfall	*1976-2007*	*1960-1975*	*Test Results*
variance	4.71	5.32	no difference
mean	6.47	4.86	no difference
Observations	32	16	

The above statistical tests were done for those years when the annual maximum discharge occurred at the Napa River near Napa station no more than one day after it occurred at the Napa River near St Helena station. Another set of statistical tests was performed using all of the available discharge data for the Napa River near Napa.

There was a significant increase in variance for the annual maximum discharge between the 1976-2007 period compared to the 1930-1975 period, at alpha =0.05. The significant increase in variance for the 1976-2007 time period compared to the 1930-1975 time period combined with the observation that there is no statistical difference in the 3-day rainfall at Angwin indicates that the watershed processes that generate the annual maximum discharge have changed. The average annual maximum discharge (peak discharge) for the Napa River near Napa showed no statistical difference (alpha = 0.05) between the 1930-1975 time period and the 1976-2007 time period. The average for the 1976-2007 period is 440 cfs greater than the average for the 1930-1975 period, a 4% increase but, this increase is not significantly.

There was a significant increase in variance for the associated daily discharge for the 1976-2007 period compared to the 1930-1975 period, at alpha =0.05. The significant increase in variance for the 1976-2007 time period compared to the 1930-1975 time period combined with the observation that there is no statistical difference in the 3-day rainfall at Angwin indicates that the watershed processes that generate the associated daily discharge have changed. The daily discharge associated with the annual maximum discharge (associated daily) for the Napa River near Napa showed no statistical difference (alpha = 0.05) between the 1930-1975 time period and the 1976-2007 time period. The average associated discharge for the 1976-2007 period was 1,053 cfs greater than for the 1930-1976 period, a 16.5% change. However, this increase was not statistically significant.

The ratio of the maximum annual discharge to the daily discharge associated with the annual maximum discharge (peak/associated daily) for the Napa River near Napa showed a statistical difference decrease (alpha = 0.05) from the 1930-1975 time period and the 1976-2007 time period. The significant change in the ratio of peak discharge to associated daily discharge indicates that the relationship between the two discharges is changing. The ratio would decrease if the peak discharge decreased or if the associated daily discharge increased. The data suggest that the associated daily discharge is increasing but that the large variance results in the change not being statistically significant. An increase in the daily discharge associated with the annual maximum discharge demonstrates that high flows in the Napa River are lasting longer and that these sustained high flows are causing more erosion. There was a significant decrease in variance of the ratio for the 1976-2007 time period compared to the 1930-1975 time period, at the alpha = 0.05 level. The decrease in variance of the ratio combined with the observation that there is no statistical difference in the 3-day rainfall at Angwin indicates that the watershed processes that generate the associated daily discharge have changed.

The above statistical analysis demonstrates that the storm discharge regime of the Napa River is changing in a way to increase the erosive power of the river. The change in the discharge regime of the Napa River must be considered when judging the cumulative impacts of storm runoff from the Tezt Vineyard Conversion project.

The changes in the storm discharge regime of the Napa River are consistent with an increase in the subsurface storm-flow discharge associated with the expansion of vineyard acreage since the mid-1970's.

Groundwater Impacts

The project description does not describe the project well or note the distances from the project well to neighboring wells. The IS/ND relies on a Phase I Water Availability Analysis to determine if there is any adverse impact to the groundwater resource. However, the County's Water Availability Analysis has never been subjected to a California Environmental Quality review so there is no evidence that the County's procedure adequately protects the groundwater resource.

The County Water Availability Analysis attempts to prevent the systematic depletion of an aquifer. The County's uses a simple rule-of-thumb method to declare that a specified per acre extraction rate is safe. This approach fails to take into account the complex nature of groundwater in mountainous coastal California. Mountainous aquifers are extremely variable in their properties. Some mountain aquifers tap porous rock, other draw water from limited fracture systems. The County's simple rule-of-thumb methodology can not accurately determine if the groundwater extraction for a specific project will have adverse impacts on the local groundwater resource. In addition, the County's approach fails to address the adverse economic impact project pumping may have on neighboring wells by lowering the groundwater surface within the project well's cone-of-depression.

Actual site-specific information about the project well and the aquifer it taps are necessary to determine if the project adversely impacts the groundwater resource.

The ECP states that the water for the vineyard will come from an existing well and spring. The spring is not mentioned anywhere else in the IS/ND. The presence of a spring on the property raises the question that project pumping may have the potential to adverse other springs in the area.

Water use for the restoration planting appears wrong. They say 0.0265 acre-feet would be used. However, that is the amount of water for a single round of watering to supply 2 gallons to each plant. Assuming a total of 12 watering cycles per year results in an annual water use 0.318 acre-feet. This value was not accounted for in the water use analysis. This amount would only be used for 3-5 years. However, it increased the required maximum pumping rate and/or duration of pumping. Increased pumping increases the potential to adversely impact neighboring wells.

Summary

Restoration of 800 feet of a blue-line stream is to be commended. However, the IS/ND presents an incomplete environmental analysis.

- The IS/ND does not mention that the Napa River is impaired for sediment.
- The diversion ditches and subsurface drains installed in the unpermitted Tezt Vineyard Conversion will cause an increase in surface storm flow.
- Conversion from oak woodland and grassland will cause an increase in subsurface storm flow.
- The increase in surface and subsurface stream flow from the Tezt project will contribute to a statistically significant increase in the storm-flow in the Napa River.
- The cumulative increase in storm-flow in the Napa River results in increased erosion of the bed and banks of the Napa River.
- The Tezt Vineyard Conversion project has the potential to decrease the caliber of the sediment discharged from the project in stormwater runoff.
- The IS/ND has not provided enough information about the Tezt well to assess the impact of project pumping on the neighboring wells and any springs that may depend on the aquifer tapped by the Tezt project.
- The ECP states that water for the vineyard is supplied by an existing well and spring. The IS/ND does not analyze weather pumping of the project well as the potential to adversely impact springs in the area.

The Napa River has been adversely impacted by increases in sediment and water discharges from all the development projects that have occurred in the watershed especially since the mid 1970's. The Napa River is cutting into its bed and eroding its banks. The Stillwater and Dietrich (2002) report, prepared as part of the TMDL process, found that two adverse impacts of erosion and sedimentation on salmon and steelhead habitat:

- Low permeability values indicating a high concentration of fine sediment in the streambed,
- Channel incision in mainstem Napa River

Channel incision is the result of the river adjusting to changes to the water and sediment discharge from its surrounding watershed. Any project that contributes an increase in water or sediment discharge, no matter how small, to the Napa River is causing an adverse environmental impact that affects the habitat of federally listed fish.

Sincerely,

Dennis Jackson
Hydrologist

References

Driscoll, Fletcher G., 1986, Groundwater and Wells, Johnson Irrigation Systems, St. Paul, MN

Jackson, Dennis, July 2009, Comments on the Napa River Sediment TMDL.

McCuen, Richard, 2003, *Modeling Hydrologic Change; Statistical Methods*, Lewis Publishers a CRC Press Company.

Napa County "Baseline Data Report, http://www.co.napa.ca.us/gov/departments/29000/bdr/index.html

Napa County Conservation Regulations http://www.co.napa.ca.us/GOV/Departments/29000/Forms/on%20line%20conservation%20reg%20brochere.pdf

Napa County Department of Public Works, August 2003, Water *Availability Analysis: Policy Report*.

Napolitano, Michael, Sandia Potter, Dyan Whyte, May 2009, *Napa River Watershed Sediment TMDL and Habitat Enhancement Plan,* San Francisco Bay Regional Water Quality Control Board.

Stillwater Sciences and W.E. Dietrich 2002. *Napa River Basin Limiting Factors Analysis*, *Final Technical Report*. Prepared for San Francisco Bay Water Quality Control Board, Oakland, California, and California State Coastal Conservancy, Oakland, California: SFBRWQCB.

Walton, William C., 1987, Groundwater Pumping Tests: Design and Analysis, Lewis Publishers, Chelsea, MI.

Comparison of Storm Discharges at the Napa River near Napa to the Storm Discharge at the Napa River near St Helena.

Prepared by Dennis Jackson, October 2009

Summary:

Statistical tests were applied to the maximum annual discharge and its associated daily discharge recorded at two USGS stream gaging stations to determine if any statistically significant change occurred between 1930-1975 and 1976-2006. The two stream gage stations are the Napa River near St Helena (upstream) and the Napa River near Napa (downstream).

The ratio of the annual maximum discharge at the downstream station was divided by the annual maximum discharge at the upstream station. This ratio is a measure of the downstream increase in streamflow. The ratio of the associated daily discharge was also calculated. Statistical tests were applied to these ratios to determine if a change in the relation between the gaging stations changed during the two time periods.

The Summary Table shows that the neither the mean nor the variance of the annual maximum discharge at the Napa River near St Helena did not change between the two time periods. The variance of the associated daily discharge is statistically different for the two time periods (alpha = 0.05) but there was no significant difference in the mean of the associated daily discharge at the St Helena station. The change in variance of the associated daily discharge demonstrates that changes in land use upstream of the St Helena gage are causing a change in the distribution of the daily discharge associated with the annual maximum discharge.

There was no statistical difference in the mean for either the annual maximum discharge or the associated daily discharge at the Napa near Napa gage (alpha = 0.05). However, there was a statistically significant difference in the variance (alpha = 0.05) for both the annual maximum discharge and the associated daily discharge at the Napa near Napa gage. The change in variance of both the annual maximum discharge and the associated daily discharge demonstrates that changes in land use upstream of the Napa near Napa gage are causing a change in the distribution of the annual maximum discharge and a change in the associated daily discharge.

There was no statistical difference in the variance of the ratio of the annual maximum discharge of the upstream station to the downstream station. There was no statistical difference in the variance of the ratio of the associated daily discharge of the upstream station to the downstream station. However, there was a statistically significant increase in the mean for both ratios (Table 4 and Table 6). This indicates that the downstream increase in annual maximum discharge was greater during the 1976-2006 period than it was during the 1930-1975 period. This increase in downstream discharge indicates that land use changes between the stream gages have increased storm runoff in the Napa River.

No statistical difference was found in either the mean or variance of the Angwin 3-day rainfall on the day of the annual maximum discharge at the Napa River near Napa. This demonstrates that changes in rainfall can not account for the changes in the discharge between 1930-1975 and 1976-2006.

Summary Table. The variance and the mean for the annual maximum discharge and the associated daily average discharge were compared for the periods 1930-1975 and 1976-2006 for two USGS gaging stations on the Napa River. The mean and variance for the ratio between the downstream-station and the upstream-station were also compared for the periods 1930-1975 and 1976-2006. All the tests used an alpha of 0.05.

Streamflow	Parameter	Napa near St Helena	Napa near Napa	Ratio Napa to St Helena
Annual Maximum Discharge	variance	equal	unequal	equal
	mean	no difference	no difference	Significant Difference
Associated Daily Discharge	variance	unequal	unequal	equal
	mean	no difference	no difference	Significant Difference

Summary of Tables 15, 16, 17 and 18. No statistical difference in Angwin 3-Day rainfall on the day of the annual maximum discharge at the Napa River near Napa.

Angwin 3-Day Rainfall	*1976-2007*	*1960-1975*	*Test Results*
variance	4.71	5.32	no difference
mean	6.47	4.86	no difference
Observations	32	16	

Station Descriptions

The U.S. Geological Survey (USGS) maintains two stream gaging stations on the Napa River. One station is located near Zinfandel Lane and is called the Napa River near St Helena. The drainage area above this station is 88.1 square-miles. The other station is at Oak Knoll Road and is called the Napa River near Napa. Its drainage area is 218 square-miles and includes the watershed above Lake Hennessey.

Procedure

The date of the annual maximum discharge at the Napa River near Napa (downstream) was compared the annual maximum discharge at the Napa River near St Helena (upstream). If the downstream peak discharge occurred more than one day after the upstream peak discharge than then it was assumed that different hydrologic processes were acting at the two stations and the events were excluded from this analysis. A total of 39 years were found to have the annual maximum discharge occur with in one day of each other at the two stations. Table 1 lists the 39 events used in this analysis.

Changes in land use have been occurring in the Napa River watershed over the last two hundred years. I assumed that the latest changes began in the mid 1970’s with the expansion of commercial vineyards. Therefore, I divided the discharge record into the pre-expansion period of 1930-1975 and to the expansion period of 1976-2006.

There are only three years of data from the early 1930's for both stations. The Napa River near St Helena discharge record resumes in 1940. The Napa River near Napa discharge record resumes in 1960. So, the 1930-1975 period is actually 1930-1932 and 1960-1975.

Dividing the annual maximum discharge at the Napa River near Napa (downstream) by the annual maximum discharge at the Napa River near St Helena (upstream) is a measure of the downstream increase in discharge. The larger the downstream-to-upstream ratio is the greater the downstream increase in annual maximum discharge. The ratios are shown in Table 1.

The maximum annual discharge is an instantaneous measurement. The discharge may be at its maximum value for only a few minutes. The daily average discharge associated with the maximum annual discharge occurs either on the day of the maximum discharge or on the next day if the maximum discharge occurred near the end of the day. I call the daily average discharge associated with the maximum annual discharge the "associated discharge".

The associated discharge is a measure of the sustained erosive power of the river. The downstream-to-upstream ratio using the associated daily discharge is another way of comparing the discharge downstream to the upstream discharge. Table 1 also contains the downstream-to-upstream ratio for the associated discharge.

The mean and variance of the downstream-to-upstream ratios were calculated for the pre-expansion period 1930-1975 and for the expansion period 1976-2006, see Table 2.

Table 3 shows that the variance of the Ratio of the Annual Maximum Discharge at the Napa River near Napa to the Annual Maximum Discharge at the Napa River near St Helena was compared for the 1930-1975 period to the 1976-2006 period. The computed F-statistic was less than the critical F-statistic at alpha = 0.05 so the variance are not statistically different.

Table 4 shows that the mean of the Ratio of the Annual Maximum Discharge at the Napa River near Napa to the Annual Maximum Discharge at the Napa River near St Helena was compared for the 1930-1975 period to the 1976-2006 period. The computed t-statistic was greater than the critical F-statistic so the variance are statistically different at the alpha = 0.05 level.

Table 5 shows that the variance of the Ratio of the Associated Daily Discharge at the Napa River near Napa to the Associated Daily Discharge at the Napa River near St Helena was compared for the 1930-1975 period to the 1976-2006 period. The computed F-statistic was less than the critical F-statistic so the variance are not statistically different at the alpha = 0.05 level

Table 6 shows that the mean of the Ratio of the Associated Daily Discharge at the Napa River near Napa to the Associated Daily Discharge at the Napa River near St Helena was compared for the 1930-1975 period to the 1976-2006 period. The computed t-statistic was greater than the critical F-statistic so the variance are statistically different at the alpha = 0.05 level.

Table 7 shows that the F-test found no statistically significant difference in the variance of the annual maximum discharge for the Napa River near St Helena between the period 1930-1975 and 1976-2006 at the alpha = 0.05 level.

Table 8 shows that no significant difference was found between the mean annual maximum discharge for the 1930-1975 period and the 1976-2006 period at the Napa River near St Helena stream gage, at the alpha =0.05 level.

Table 9 shows that the F-test found a statistically significant difference in the variance of the associated daily discharge for the Napa River near St Helena between the period 1930-1975 and 1976-2006 at the alpha = 0.05 level.

Table 10 shows that no significant difference was found between the mean associated daily discharge for the 1930-1975 period and the 1976-2006 period at the Napa River near St Helena stream gage, at the alpha =0.05 level.

Table 11 shows that the F-test found a statistically significant difference in the variance of the annual maximum discharge for the Napa River near Napa between the period 1930-1975 and 1976-2006 at the alpha = 0.05 level.

Table 12 shows that no significant difference was found between the mean annual maximum discharge for the 1930-1975 period and the 1976-2006 period at the Napa River near Napa stream gage, at the alpha =0.05 level.

Table 13 shows that the F-test found a statistically significant difference in the variance of the associated daily discharge for the Napa River near Napa between the period 1930-1975 and 1976-2006 at the alpha = 0.05 level.

Table 14 shows that no significant difference was found between the mean associated daily discharge for the 1930-1975 period and the 1976-2006 period at the Napa River near Napa stream gage, at the alpha =0.05 level.

The above statistical tests were done for those years when the annual maximum discharge occurred at the Napa River near Napa station no more than one day after it occurred at the Napa River near St Helena station. Another set of statistical tests was performed using all of the available discharge data for the Napa River near Napa.

Table 19 shows that there was a significant increase in variance for the annual maximum discharge between the 1976-2007 period compared to the 1930-1975 period, at alpha =0.05. The significant increase in variance for the 1976-2007 time period compared to the 1930-1975 time period combined with the observation that there is no statistical difference in the 3-day rainfall at Angwin indicates that the watershed processes that generate the annual maximum discharge have changed. The average annual maximum discharge (peak discharge) for the Napa River near Napa showed no statistical difference (alpha = 0.05) between the 1930-1975 time period and the 1976-2007 time period. The average for the 1976-2007 period is 440 cfs greater than the average for the 1930-1975 period, a 4% increase but, this increase is not significantly.

Table 20 shows that there was a significant increase in variance for the associated daily discharge for the 1976-2007 period compared to the 1930-1975 period, at alpha =0.05. The significant increase in variance for the 1976-2007 time period compared to the 1930-1975 time period combined with the observation that there is no statistical difference in the 3-day rainfall at Angwin indicates that the watershed processes that generate the associated daily discharge have changed. The daily discharge associated with the annual maximum discharge (associated daily) for the Napa River near Napa showed no statistical difference (alpha = 0.05) between the 1930-1975 time period and the 1976-2007 time period. The average associated discharge for the 1976-2007 period was 1,053 cfs greater than for the 1930-1976 period, a 16.5% change. However, this increase was not statistically significant.

The ratio of the maximum annual discharge to the daily discharge associated with the annual maximum discharge (peak/associated daily) for the Napa River near Napa showed a statistical difference decrease (alpha = 0.05) from the 1930-1975 time period and the 1976-2007 time period (Table 21). The significant change in the ratio of peak discharge to associated daily discharge indicates that the relationship between the two discharges is changing. The ratio would decrease if the peak discharge decreased or if the associated daily discharge increased. Tables 19 and 20 suggest that the associated daily discharge is increasing. An increase in the daily discharge associated with the annual maximum discharge demonstrates that high flows in the Napa River are lasting longer. There was a significant decrease in variance of the ratio for the 1976-2007 time period compared to the 1930-1975 time period, at the alpha = 0.05 level. The decrease in variance of the ratio combined with the observation that there is no statistical difference in the 3-day rainfall at Angwin indicates that the watershed processes that generate the associated daily discharge have changed.

Table 1. Annual maximum discharge at the Napa River near St Helena and the Napa River near Napa that occur within one day of each are assumed to represent a single hydrologic process. Other years were excluded from this analysis because the difference in timing of the peak events suggest that different hydrologic processes were acting at the two gages.

Water Year	Date of Peak	**Napa near St Helena** Annual Maximum Discharge	**Napa near St Helena** Associated Daily	Annual Max Napa/St Helena	Assoc Daily Napa/St Helena	Date of Peak	**Napa near Napa** Annual Maximum Discharge	**Napa near Napa** Associated Daily
1930	12/15/1929	4480	3610	1.49	1.05	12/15/1929	6660	3780
1931	1/23/1931	920	443	1.63	1.60	1/23/1931	1500	709
1932	12/27/1931	5980	4240	1.94	2.21	12/27/1931	11600	9370
1960	2/8/1960	11600	5820	1.06	1.43	2/8/1960	12300	8300
1961	1/31/1961	2160	1020	1.55	1.57	1/31/1961	3350	1600
1963	1/31/1963	12300	7160	2.03	1.55	1/31/1963	25000	11100
1964	1/20/1964	5020	1360	1.05	1.72	1/20/1964	5260	2340
1965	1/5/1965	11800	5540	1.53	1.47	1/5/1965	18100	8170
1966	1/5/1966	9190	5390	1.21	1.62	1/5/1966	11100	8730
1967	1/21/1967	11100	8380	1.93	1.44	1/21/1967	21400	12100
1968	1/29/1968	4970	2010	1.73	2.11	1/29/1968	8620	4250
1969	1/13/1969	6600	4640	1.33	1.45	1/13/1969	8760	6720
1970	1/24/1970	9450	4390	1.56	2.28	1/24/1970	14700	9990
1971	12/3/1970	9700	4920	1.26	1.66	12/4/1970	12200	8150
1972	12/27/1971	1120	482	1.28	1.57	12/27/1971	1430	757
1973	1/16/1973	11300	3400	1.23	2.49	1/16/1973	13900	8450
1974	3/30/1974	6680	3160	1.46	2.01	3/30/1974	9730	6350
1975	3/21/1975	8540	2410	1.26	2.02	3/22/1975	10800	4880
1976	2/29/1976	203	67	1.58	2.37	3/1/1976	321	159
1978	1/16/1978	10000	4900	1.53	2.08	1/16/1978	15300	10200
1979	1/11/1979	2480	1190	2.54	2.62	1/11/1979	6310	3120
1980	2/17/1980	7200	3100	1.74	2.47	2/18/1980	12500	7650
1981	1/27/1981	3660	2320	1.31	1.20	1/27/1981	4780	2790
1984	12/25/1983	9060	4590	1.35	1.93	12/25/1983	12200	8860
1985	2/8/1985	7390	3230	1.27	1.74	2/8/1985	9360	5610
1986	2/17/1986	16900	13700	2.20	1.58	2/18/1986	37100	21600
1987	2/13/1987	2730	1300	1.78	2.11	2/13/1987	4870	2740
1988	1/4/1988	1390	1170	1.65	1.58	1/4/1988	2290	1850
1989	3/11/1989	3730	1690	1.31	1.56	3/11/1989	4890	2640
1990	2/16/1990	1370	608	1.37	1.40	2/16/1990	1880	853
1991	3/4/1991	6940	3600	1.30	1.61	3/4/1991	8990	5790
1992	2/20/1992	2890	1300	1.61	2.28	2/20/1992	4660	2970
1993	1/20/1993	7930	4610	1.64	1.69	1/20/1993	13000	7780
1994	2/20/1994	900	577	1.80	2.24	2/20/1994	1620	1290
1995	3/9/1995	11100	7330	2.94	2.61	3/9/1995	32600	19100
2001	3/4/2001	3280	1170	1.32	2.03	3/5/2001	4320	2370
2003	12/16/2002	10200	4670	1.87	2.61	12/16/2002	19100	12200
2005	3/22/2005	3890	2090	1.57	1.97	3/22/2005	6090	4110
2006	12/31/2005	18300	10600	1.62	2.27	12/31/2005	29600	24100

Table 2. Summary statistics for the 1930-1975 period and the 1976-2006 period. Events that occur within one day of each are assumed to represent a single hydrologic process. Other years were excluded from this analysis because the difference in timing of the peak events suggest that different hydrologic processes were acting at the two gages.

1930-1975	**Napa near St Helena** Annual Maximum Discharge	**Napa near St Helena** Associated Daily	Annual Max Napa/St Helena	Assoc Daily Napa/St Helena	**Napa near Napa** Annual Maximum Discharge	**Napa near Napa** Associated Daily
count	18	18	18	18	18	18
average	7,383.89	3,798.61	1.47	1.74	10,911.67	6430.33
variance	13,885,790	5,065,073	0.087	0.136	40,265,003	12,550,939
Std dev	3,726.36	2,250.57	0.29	0.37	6,345.47	3,542.73

1976-2006	**Napa near St Helena** Annual Maximum Discharge	**Napa near St Helena** Associated Daily	Annual Max Napa/St Helena	Assoc Daily Napa/St Helena	**Napa near Napa** Annual Maximum Discharge	**Napa near Napa** Associated Daily
Count	21	21	21	21	21	21
average	6,263.95	3,514.86	1.68	2.00	11,037.19	7,037.24
variance	25,158,486	11,816,492	0.182	0.179	109,890,210	47,839,733
Std dev	5,015.82	3,437.51	0.43	0.42	10,482.85	6,916.63

Table 3. The variance of the Ratio of the Annual Maximum Discharge at the Napa River near Napa to the Annual Maximum Discharge at the Napa River near St Helena was compared for the 1930-1975 period to the 1976-2006 period. The computed F-statistic was less than the critical F-statistic at alpha = 0.05 so the variance are not statistically different.

F-Test Two-Sample for Variances

Ratio of Annual Maximum Discharges	*1976-2006*	*1930-1975*
Mean	1.680	1.473
Variance	0.182	0.087
Observations	21	18
df	20	17
F	2.097	
P(F<=f) one-tail	0.064	
F Critical one-tail	2.230	

Table 4. The mean of the Ratio of the Annual Maximum Discharge at the Napa River near Napa to the Annual Maximum Discharge at the Napa River near St Helena was compared for the 1930-1975 period to the 1976-2006 period. The computed t-statistic was greater than the critical t-statistic so the means are statistically different at the alpha = 0.05 level. The mean of the second time period is greater than for the 1930-1975 period.

t-Test: Two-Sample Assuming Equal Variances

Ratio of Annual Maximum Discharges	*1976-2006*	*1930-1975*
Mean	1.680	1.473
Variance	0.182	0.087
Observations	21	18
Pooled Variance	0.1385	
Hypothesized Mean Difference	0	
df	37	
t Stat	1.727	
P(T<=t) one-tail	0.046	
t Critical one-tail	1.687	
P(T<=t) two-tail	0.092	
t Critical two-tail	2.026	

Table 5. The variance of the Ratio of the Associated Daily Discharge at the Napa River near Napa to the Associated Daily Discharge at the Napa River near St Helena was compared for the 1930-1975 period to the 1976-2006 period. The computed F-statistic was less than the critical F-statistic so the variance are not statistically different at the alpha = 0.05 level.

F-Test Two-Sample for Variances

Ratio of Associated Daily Discharges	***1976-2006***	***1930-1975***
Mean	1.997	1.736
Variance	0.179	0.136
Observations	21	18
df	20	17
F	1.316	
P(F<=f) one-	0.286	
F Critical one-	2.230	

Table 6. The mean of the Ratio of the Associated Daily Discharge at the Napa River near Napa to the Associated Daily Discharge at the Napa River near St Helena was compared for the 1930-1975 period to the 1976-2006 period. The computed t-statistic was greater than the critical t-statistic so the means are statistically different at the alpha = 0.05 level.

t-Test: Two-Sample Assuming Equal Variances

Ratio of Associated Daily Discharges	*1976-2006*	*1930-1975*
Mean	1.997	1.736
Variance	0.179	0.136
Observations	21	18
Pooled Variance	0.159	
Hypothesized Mean Difference	0	
df	37	
t Stat	2.039	
P(T<=t) one-tail	0.024	
t Critical one-tail	1.687	
P(T<=t) two-tail	0.049	
t Critical two-tail	2.026	

Table 7. The F-test found no statistically significant difference in the variance of the annual maximum discharge for the Napa River near St Helena between the period 1930-1975 and 1976-2006 at the alpha = 0.05 level.

F-Test Two-Sample for Variances

Annual Maximum Discharge	*1976-2006*	*1930-1975*
Mean	6,263.95	7,383.89
Variance	25,158,486	13,885,790
Observations	21	18
df	20	17
F	1.812	
P(F<=f) one-tail	0.110	
F Critical one-tail	2.230	

Table 8. No significant difference was found between the mean annual maximum discharge for the 1930-1975 period and the 1976-2006 period at the Napa River near St Helena stream gage, at the alpha =0.05 level.

t-Test: Two-Sample Assuming Equal Variances

Annual Maximum Discharge	*1976-2006*	*1930-1975*
Mean	6,263.95	7,383.89
Variance	25,158,486	13,885,790
Observations	21	18
Pooled Variance	19,979,139	
Hypothesized Mean Difference	0	
df	37	
t Stat	-0.780	
P(T<=t) one-tail	0.220	
t Critical one-tail	1.687	
P(T<=t) two-tail	0.440	
t Critical two-tail	2.026	

Table 9. The F-test found a statistically significant difference in the variance of the associated daily discharge for the Napa River near St Helena between the period 1930-1975 and 1976-2006 at the alpha = 0.05 level.

F-Test Two-Sample for Variances

Napa near St Helena

Associated Daily Discharge	*1976-2006*	*1930-1975*
Mean	3,514.86	3,798.61
Variance	11,816,492	5,065,073
Observations	21	18
Df	20	17
F	2.333	
P(F<=f) one-tail	0.041	
F Critical one-tail	2.230	

Table 10. No significant difference was found between the mean associated daily discharge for the 1930-1975 period and the 1976-2006 period at the Napa River near St Helena stream gage, at the alpha =0.05 level.

t-Test: Two-Sample Assuming Unequal Variances

Napa near St Helena

Associated Daily Discharge	*1976-2006*	*1930-1975*
Mean	3,514.86	3,798.61
Variance	11,816,492	5,065,073
Observations	21	18
Hypothesized Mean Difference	0	
df	35	
t Stat	-0.309	
P(T<=t) one-tail	0.380	
t Critical one-tail	1.690	
P(T<=t) two-tail	0.759	
t Critical two-tail	2.030	

Table 11. The F-test found a statistically significant difference in the variance of the annual maximum discharge for the Napa River near Napa between the period 1930-1975 and 1976-2006 at the alpha = 0.05 level.

F-Test Two-Sample for Variances

Napa near Napa

Annual Maximum Discharge	*1976-2006*	*1930-1975*
Mean	11,037.19	10,911.67
Variance	109,890,210	40,265,003
Observations	21	18
Df	20	17
F	2.729	
P(F<=f) one-tail	0.021	
F Critical one-tail	2.230	

Table 12. No significant difference was found between the mean annual maximum discharge for the 1930-1975 period and the 1976-2006 period at the Napa River near Napa stream gage, at the alpha =0.05 level.

t-Test: Two-Sample Assuming Unequal Variances

Napa near Napa

Annual Maximum Discharge	*1976-2006*	*1930-1975*
Mean	11,037.19	10,911.67
Variance	109,890,210	40,265,003
Observations	21	18
Hypothesized Mean Difference	0	
Df	34	
t Stat	0.046	
P(T<=t) one-tail	0.482	
t Critical one-tail	1.691	
P(T<=t) two-tail	0.964	
t Critical two-tail	2.032	

Table 13. The F-test found a statistically significant difference in the variance of the associated daily discharge for the Napa River near Napa between the period 1930-1975 and 1976-2006 at the alpha = 0.05 level.

F-Test Two-Sample for Variances

Napa near Napa

Associated Daily Discharge	*1976-2006*	*1930-1975*
Mean	7,037.24	6,430.33
Variance	47,839,733	12,550,939
Observations	21	18
Df	20	17
F	3.812	
P(F<=f) one-tail	0.004	
F Critical one-tail	2.230	

Table 14. No significant difference was found between the mean associated daily discharge for the 1930-1975 period and the 1976-2006 period at the Napa River near Napa stream gage, at the alpha =0.05 level.

t-Test: Two-Sample Assuming Unequal Variances

Napa near Napa

Associated Daily Discharge	*1976-2006*	*1930-1975*
Mean	7,037.24	6,430.33
Variance	47,839,733	12,550,939
Observations	21	18
Hypothesized Mean Difference	0	
Df	31	
t Stat	0.352	
P(T<=t) one-tail	0.364	
t Critical one-tail	1.696	
P(T<=t) two-tail	0.727	
t Critical two-tail	2.040	

Table 15. Three day rainfall totals at Angwin on the day of the annual maximum discharge at the Napa River near Napa station.

Date of Peak Discharge at Napa near Napa	Angwin 3-Day Rainfall on Day of Peak
2/8/1960	6.78
1/31/1961	3.20
2/15/1962	6.16
1/31/1963	10.78
1/20/1964	4.48
1/5/1965	4.37
1/5/1966	6.88
1/21/1967	7.42
1/29/1968	2.21
1/13/1969	6.60
1/24/1970	6.11
12/4/1970	6.06
12/27/1971	2.77
1/16/1973	4.15
3/30/1974	4.39
3/22/1975	2.83
3/1/1976	1.70
3/16/1977	2.36
1/16/1978	6.12
1/11/1979	4.79
2/18/1980	7.39
1/27/1981	3.14
1/4/1982	3.32
3/1/1983	6.27
12/25/1983	6.47
2/8/1985	4.75
2/18/1986	11.60
2/13/1987	4.36
1/4/1988	0.03
3/11/1989	2.71
2/16/1990	1.57
3/4/1991	6.79
2/20/1992	2.56
1/20/1993	4.66
2/20/1994	1.74
3/9/1995	7.88
2/4/1996	4.44
1/1/1997	8.29
2/3/1998	5.72
2/9/1999	3.71
2/14/2000	2.78
3/5/2001	2.47
1/2/2002	3.98
12/16/2002	8.70
2/18/2004	5.32
3/22/2005	3.09
12/31/2005	8.18
2/11/2007	3.85

Table 16. Angwin 3-day total rainfall on day of annual maximum at Napa River near Napa.

	1960-1975	1976-2007
count	16	32
Average	5.32	4.71
Variance	4.86	6.47

Table 17. There is no statistical difference in the variance for the Angwin 3-Day rainfall on the day of the annual maximum discharge at the Napa River near Napa at the alpha = 0.05 level..

F-Test Two-Sample for Variances

Angwin 3-Day Rainfall	*1976-2007*	*1960-1975*
Mean	4.71	5.32
Variance	6.47	4.86
Observations	32	16
df	31	15
F	1.3314	
P(F<=f) one-tail	0.2833	
F Critical one-tail	2.2414	

Table 18. There is no statistical difference in the mean for the Angwin 3-Day rainfall on the day of the annual maximum discharge at the Napa River near Napa at the alpha = 0.05 level.

t-Test: Two-Sample Assuming Equal Variances

Angwin 3-Day Rainfall	*1976-2007*	*1960-1975*
Mean	4.71	5.32
Variance	6.47	4.86
Observations	32	16
Pooled Variance	5.9491	
Hypothesized Mean Difference	0	
df	46	
t Stat	-0.8219	
P(T<=t) one-tail	0.2077	
t Critical one-tail	1.6787	
P(T<=t) two-tail	0.4154	
t Critical two-tail	2.0129	

Table 19. There was a significant increase in variance for the annual maximum discharge between the 1976-2007 period compared to the 1930-1975 period, at alpha =0.05. The significant increase in variance for the 1976-2007 time period compared to the 1930-1975 time period combined with the observation that there is no statistical difference in the 3-day rainfall at Angwin indicates that the watershed processes that generate the annual maximum discharge have changed. The average annual maximum discharge (peak discharge) for the Napa River near Napa showed no statistical difference (alpha = 0.05) between the 1930-1975 time period and the 1976-2007 time period. The average for the 1976-2007 period is 440 cfs greater than the average for the 1930-1975 period, a 4% increase but, this increase is not significantly.

F-Test Two-Sample for Variances

Peak Discharge	*1976-2007*	*1930-1975*
Mean	11,256	10,816
Variance	86,901,229	38,202,715
Observations	32	19
df	31	18
F	2.2747	
P(F<=f) one-tail	0.0348	
F Critical one-tail	2.1015	

t-Test: Two-Sample Assuming Unequal Variances

Peak Discharge	*1976-2007*	*1930-1975*
Mean	11,256	10,816
Variance	86,901,229	38,202,715
Observations	32	19
Hypothesized Mean Difference	0	
df	48	
t Stat	0.2024	
P(T<=t) one-tail	0.4202	
t Critical one-tail	1.6772	
P(T<=t) two-tail	0.8405	
t Critical two-tail	2.0106	

Table 20. There was a significant increase in variance for the associated daily discharge for the 1976-2007 period compared to the 1930-1975 period, at alpha =0.05. The significant increase in variance for the 1976-2007 time period compared to the 1930-1975 time period combined with the observation that there is no statistical difference in the 3-day rainfall at Angwin indicates that the watershed processes that generate the associated daily discharge have changed. The daily discharge associated with the annual maximum discharge (associated daily) for the Napa River near Napa showed no statistical difference (alpha = 0.05) between the 1930-1975 time period and the 1976-2007 time period. The average associated discharge for the 1976-2007 period was 1,053 cfs greater than for the 1930-1976 period, a 16.5% change. However, this increase was not statistically significant.

F-Test Two-Sample for Variances

Associated Daily	*1976-2007*	*1930-1975*
Mean	7,444	6,391
Variance	39,544,415	11,882,512
Observations	32	19
df	31	18
F	3.3280	
P(F<=f) one-tail	0.0047	
F Critical one-tail	2.1015	

t-Test: Two-Sample Assuming Unequal Variances

Associated Daily	*1976-2007*	*1930-1975*
Mean	7,444	6,391
Variance	39,544,415	11,882,512
Observations	32	19
Hypothesized Mean Difference	0	
df	49	
t Stat	0.7716	
P(T<=t) one-tail	0.2220	
t Critical one-tail	1.6766	
P(T<=t) two-tail	0.4441	
t Critical two-tail	2.0096	

Table 21. The ratio of the maximum annual discharge to the daily discharge associated with the annual maximum discharge (peak/associated daily) for the Napa River near Napa showed a statistical difference decrease (alpha = 0.05) from the 1930-1975 time period and the 1976-2007 time period. The significant change in the ratio of peak discharge to associated daily discharge indicates that the relationship between the two discharges is changing. The ratio would decrease if the peak discharge decreased or if the associated daily discharge increased. Tables 19 and 20 suggest that the associated daily discharge is increasing. An increase in the daily discharge associated with the annual maximum discharge demonstrates that high flows in the Napa River are lasting longer. There was a significant decrease in variance of the ratio for the 1976-2007 time period compared to the 1930-1975 time period, at the alpha = 0.05 level. The decrease in variance of the ratio combined with the observation that there is no statistical difference in the 3-day rainfall at Angwin indicates that the watershed processes that generate the associated daily discharge have changed.

F-Test Two-Sample for Variances

Ratio Peak/Assoc Daily	***1930-1976***	***1976-2007***
Mean	1.7697	1.5906
Variance	0.1255	0.0631
Observations	19	32
df	18	31
F	1.9871	
P(F<=f) one-tail	0.0452	
F Critical one-tail	1.9481	

t-Test: Two-Sample Assuming Unequal Variances

Ratio Peak/Assoc Daily	***1930-1976***	***1976-2007***
Mean	1.7697	1.5906
Variance	0.1255	0.0631
Observations	19	32
Hypothesized Mean Difference	0	
df	29	
t Stat	1.9340	
P(T<=t) one-tail	0.0315	
t Critical one-tail	1.6991	
P(T<=t) two-tail	0.0629	
t Critical two-tail	2.0452	