

**Empirical Peak Flow Reduction Model for the
Watershed-wide Waste Discharge Requirements for Elk River
and Freshwater Creek, Humboldt County, California**



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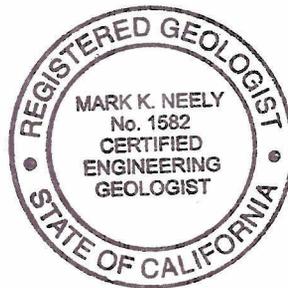


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Introduction

This technical report presents the empirical peak flow reduction model and methodology utilized by the Regional Water Quality Control Board (Regional Water Board) staff for the Watershed-wide Waste Discharge Requirements (WWDRs) for Elk River and Freshwater Creek, Humboldt County, California. While flooding is a natural occurrence in any watershed, discharges of sediment and the removal of tree canopy have combined to reduce channel capacity and increase peak flows in a manner that substantially increases the frequency, magnitude, and duration of flooding in Elk River and Freshwater Creek. Flooding in these watersheds creates significant health and safety problems, preventing people from getting to and from their homes, schools and jobs, as well as inundating houses, bridges and roads, and septic systems.

Restoring channel capacity is the primary way to eliminate the nuisance flooding occurring in these watersheds. Figure 1 shows that there are other partial solutions to the goal. Reducing peak flows is only a partial solution since the largest cause of nuisance flooding is the loss of channel capacity. Improving infrastructure, such as the bridges, is also a partial solution since it will only improve some of the structures that are being affected by flooding and it won't address other water quality impacts related to the increased flooding. Therefore, restoring the channel capacity is the only way to eliminate nuisance flooding. However, since natural recovery would take a very long time (in the order of many decades to centuries), some type of assisted recovery for the channel capacity is appropriate to alleviate the nuisance flooding.

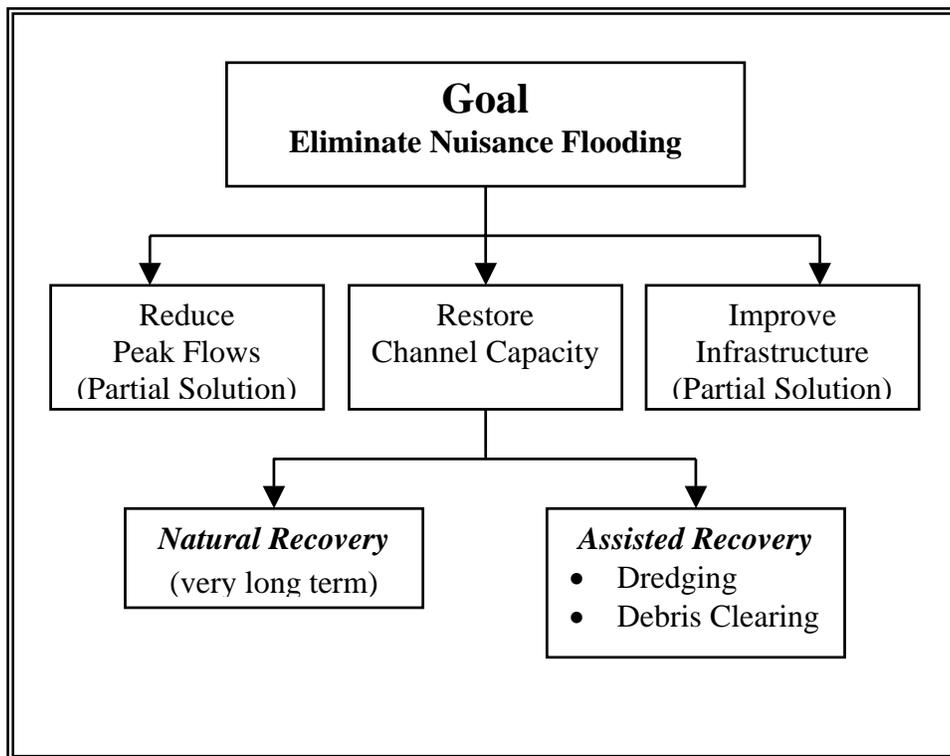


Figure 1. Achieving the overall goals for the watershed.

Abatement of the nuisance flooding by physically removing built-up sediment and streamside vegetation, thereby increasing channel capacity and allowing peak flows to move through these systems without overtopping channel banks has long been discussed as a potential solution. In response to Regional Water Board direction in December 2003, Regional Water Board staff (hereinafter staff) met with various permitting and potential funding entities to evaluate options for instream sediment removal in these watersheds. Staff concluded that a feasibility study would be required prior to taking any action. Staff further determined that no funding, public or private, was available for study preparation or implementation, nor was any entity prepared to accept lead responsibility. PALCO expressed an interest in pursuing sediment removal options in April 2002 as part of Regional Water Board sponsored mediation attempts. However, no specific proposals have been submitted to the Regional Water Board. PALCO indicated a renewed interest in pursuing restoration of the channel capacity or improving the infrastructure in March of 2005. Although PALCO is providing some funding for a feasibility study, no plan exists to increase channel capacity or improve infrastructure in the foreseeable future.

The application of the empirical peak flow reduction model (peak flow model) as proposed by staff in the WWDRs does not directly address the elimination of nuisance flooding. Figure 2 shows that the goal of the permit is to control incremental increases in peak flows by reducing canopy removal rates and thereby reducing the volume of storm water runoff from future harvest areas. This rate can be adjusted by adaptive management depending on monitoring results or if channel capacity is restored or infrastructure is improved.

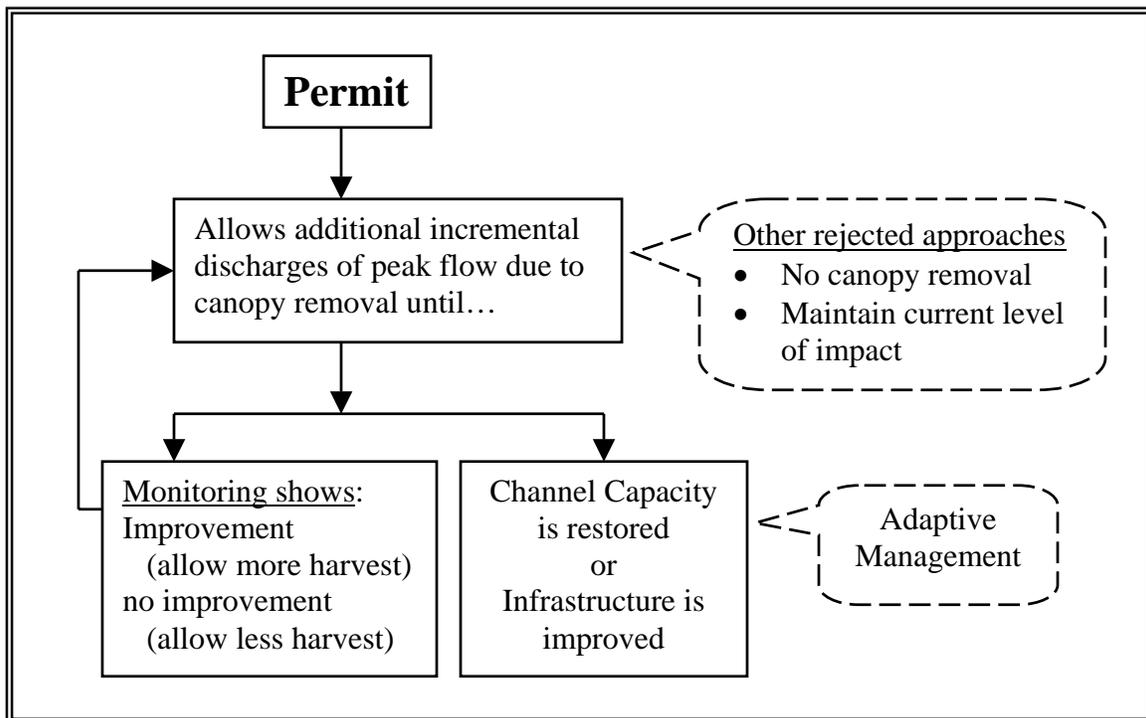


Figure 2. Description of the application of the peak flow model.

The peak flow model is employed to reduce the predicted magnitude, frequency, and duration of nuisance flooding events from current conditions over time by reducing canopy removal. This

approach builds upon previous efforts to limit peak flow increases by incorporating new data, protecting beneficial uses of water and lessening the nuisance flooding conditions.

Work Conducted by California Licensed Professionals

The work described in this report constitutes the practices of geology and civil engineering, according to the California Professional Engineers Act (California Business and Professions Code §§ 6700-6799, 2005), the Geologist and Geophysicist Act (California Business and Professions Code §§ 7800-7887, 2005), and associated rules and regulations. The work has been performed by a team of California licensed professional engineers and geologists on staff at the Regional Water Board. These individuals include, but are not limited to, Matthew Buffleben, P.E. # C65694; Adona White, P.E. # C68111; and Mark Neely, C.E.G. # 1572

Background

Effects of flooding

Frequent flooding limits the residents' ingress and egress to their property. In particular, the US Army Corps of Engineers (1975), in their report on flooding in Freshwater Creek, described several potential hazards: people can become trapped in their homes or vehicles; the force of the floodwaters and debris deposits can rupture waterlines and risk contamination of domestic water supplies; and isolation of areas by floodwater creates hazards in terms of medical, fire, or law enforcement emergencies.

Property damage includes fences being knocked down during floods, loss of agricultural productivity through deposition of silt on crops, threats to septic systems, loss of water supplies by filling of pools with sediment, and wear and failure of pumps and other mechanical devices. When floodwaters enter homes, they cause damage to floorings, furniture, walls, etc. and require residents to raise furniture and property for its protection. Cleanup after a flood event is costly and time-consuming. Residents attempt to protect their homes from floodwaters by using sandbags or by constructing walls and levees. Due to increased risk of flooding, property values are reduced and flood insurance is difficult to obtain and expensive to maintain.

Nuisance expresses itself in different forms: emotional and psychological distress of floodwaters entering a property or home, financial hardship, and anxiety. All of these effects constitute a nuisance condition.

Freshwater Creek and Elk River

Residents downstream of PALCO's timber harvesting activities in Elk River and Freshwater Creek filed formal complaints with the Regional Water Board (and other State agencies) contending the increased magnitude (i.e. water surface elevation) and frequency of flooding in the lower portion of the two watersheds have and are continuing to significantly affect the beneficial uses of water and the public health and safety of downstream residents. They also reported significant changes in stream morphology, such as the filling of in-stream pools with sediment corresponding with sediment discharges from upstream timber harvesting activities. Subsequent staff evaluations, monitoring efforts, and reports have corroborated these resident reports.

The increased frequency and magnitude of flooding in Elk River and Freshwater Creek results primarily from a combination of two factors: reduced channel capacity and altered hydrology. A decrease in channel capacity has been documented in Elk River (Patenaude 2004) and in Freshwater Creek (Caltrans 2003). Studies from Caspar Creek experimental watershed confirm that peak flow response to logging results from the reduction in vegetative cover. Reducing vegetative cover, particularly large trees, reduces evapotranspiration and rainfall interception (Ziemer 1998). Hydrology is also altered by changes that lower infiltration (for example, from compaction of soil) and increase the stream network (for example, construction of inside road ditches and gullies) in the watershed.

Waste Discharge Requirements

Waste Discharge Requirements must implement the Basin Plan, which prohibits the discharge of sediment waste from timber harvest-related activities in amounts deleterious to beneficial uses (*Water Quality Control Plan for the North Coast Region* (Basin Plan): pp. 4-28 – 4-30), and must be crafted to address the need to prevent nuisance (Water Code section 13263(a)).

California Water Code section 13050 defines nuisance to mean anything, which meets all of the following requirements:

- (1) Is injurious to health, or is indecent or offensive to the senses, or an obstruction to the free use of property, so as to interfere with the comfortable enjoyment of life or property.
- (2) Affects at the same time an entire community or neighborhood, or any considerable number of persons, although the extent of the annoyance or damage inflicted upon individuals may be unequal.
- (3) Occurs during, or as a result of, the treatment or disposal of waste.

Since the criteria of Water Code section 13050 are met, it is the right and responsibility of the Regional Water Board to control the nuisance flooding in Freshwater Creek and Elk River. Based on the extensive documentation of nuisance flooding, the relationship of increased peak flows to canopy removal, and the obligation of the Regional Water Board to address nuisance and to protect beneficial uses, staff is recommending a application of the peak flow reduction model in a manner that will reduce flooding when applied to the Elk River and Freshwater Creek watersheds through the WWDRs.

Empirical Peak Flow Reduction Model

To reduce nuisance conditions, staff determined that the use of the empirical peak flow reduction model (peak flow model) was the most appropriate for use in the Elk River and Freshwater Creek watersheds. Staff selected a peak flow model that relates the effects of vegetation removal to increases in peak flow, based on studies in the Caspar Creek watershed in Mendocino County. Staff then identified the values for key parameters in the peak flow model that includes a margin of safety and accounts for seasonality (wet versus dry soil conditions). Finally, staff modeled future conditions to determine appropriate reduction of the current nuisance conditions.

For the purposes of the WWDRs, and where possible, it is those flood waters that inundate key points on roads limiting numerous residents from free movement that are targeted. This threshold is defined by staff as the threshold for nuisance.

Peak flow model background

In selecting an appropriate model to address peak flow conditions associated with vegetation removal, staff used the peak flow model developed from results of the Caspar Creek Experimental Watershed by the scientists at the USDA Forest Service Redwood Sciences Laboratory (peak flow model).

There are several reasons why staff, as well as PALCO and CDF, use the Caspar Creek peak flow model. Caspar Creek (Mendocino County) is one of the most intensively studied watersheds in the northern California coast and Pacific Northwest, and has substantially advanced the scientific understanding of forest hydrology and sediment delivery. The Caspar Creek study is uniquely appropriate because it evaluated the hydrologic effects of conducting timber harvest and related activities in second-growth redwood forests. Also, Caspar Creek is representative of conditions in many northern California coast watersheds. The Caspar Creek watershed is similar to the Elk River and Freshwater Creek watersheds in terms of its coastal location, vegetation, rainfall patterns, and land use.

This peak flow model has been previously used for evaluating and regulating runoff from timber harvest activities in both Freshwater Creek and Elk River. Pacific Lumber Company (PALCO 2000) adapted equations from the published results of the Caspar Creek experiment (Lewis et al. 2001) and utilized them for conducting the watershed analysis required under their Habitat Conservation Plan (HCP). Lisle et al. (2000a) reviewed the flooding analysis for the watersheds to determine, in part, the hydrologic changes resulting from past and future timber harvesting. In response to a request by California Department of Forestry and Fire Protection (CDF), the authors issued *Addendum: Review of Freshwater Flooding Analysis Summary* (Lisle et al. 2000b) and provided a systematic explanation of how to apply the equations presented in PALCO 2000. CDF subsequently conducted analyses in both Freshwater Creek (Munn 2001) and Elk River (Munn 2002) to determine a canopy removal rate that would not result in an increase in peak flow over the current (2001/2002) conditions. In 2001 and 2002 respectively, CDF imposed allowable clearcut equivalent acreage limitations in the Freshwater Creek and Elk River watersheds. The CDF imposed limitations included 500 clearcut equivalent acres in Freshwater Creek and 600 clearcut equivalent acres in Elk River annually.

The peak flow model is helpful in guiding decisions regarding timber-harvest related runoff, because of its ability to track effects of timber operations from year to year, and its ease of use and objectivity. Although process-based models are preferred for many modeling exercises, using an empirical model in these watersheds is appropriate at this time. Process-based models require extensive input data due to the complexity of modeling hydrology and hydraulics. While watershed information is more abundant in the Elk River and Freshwater Creek watersheds than most other north coast watersheds, there is not sufficient data to allow for process-based modeling of the effects of timber harvesting on peak flows. As new data are developed, it may become more appropriate to consider process-based models in these watersheds. Until that time, staff believes that using an empirical model that does not require extensive data inputs is appropriate.

Description of the Caspar Creek Study and Results

In 1985, monitoring began for a new phase of timber harvest that was about to occur in North Fork Caspar Creek. Controlled experiments in Caspar Creek were designed and conducted to measure changes in hydrology and sediment transport resulting from timber harvesting activities. Monitoring data were collected over four years of pretreatment¹. Timber harvests were conducted primarily over a three-year period (1989 – 1991) and were monitored for at least four more years. Treatment for the eight harvest units was comprised of clearcut harvesting of 30% to 98% of treated watersheds, of which 81% were cable yarded and 19% tractor yarded. Additionally, 34% of the harvested timber was selectively logged from stream buffer zones, ranging from 15 - 46 m in width, depending on stream class. Treatments included construction of new roads, landings, and skid trails, as well as broadcast burning of four harvest units. Three tributaries were left as control watersheds. In all, fifteen gaging stations were monitored, including one on South Fork, five on North Fork, and nine on tributaries of North Fork (Lewis et al. 2001).

The peak flow model is based on the results from the observations of increases in peak flows following timber harvest activities. The analysis included 59 storms on 10 treated watersheds. Storm events were included when they had a recurrence interval of more than 7 times per year although a few smaller peaks were included in dry years (Lewis et al. 2001). Although monitoring was discontinued in several of the watersheds in 1996, Lewis and Keppeler (in press) report the results where monitoring was continued through hydrologic year 2003.

Runoff volumes vary with seasonal conditions, even for the same precipitation event. Lewis et al. (2001) used a wetness index to reflect seasonal differences. The wetness index is based on mean daily average stream flows in the South Fork Caspar Creek (a control watershed, unlogged since 1973). The decision to use streamflow rather than precipitation to calculate antecedent wetness conditions was based on the assumption that the history of the streamflow response would be a better predictor of streamflow than would the history of rainfall (Lewis et al. 2001). Furthermore, the wetness index was developed to reflect the soil moisture changes between the harvested and control areas that develop due to harvesting. The wetness of the watershed is calculated per Equation 1 where the daily discharges were accumulated and decayed using a 30-day half-life.

$$w_i = Aw_{i-1} + q_i \quad \text{Equation 1}$$

Where,

w_i = Wetness on day i

q_i = The daily mean flow at South Fork Caspar Creek on day i (cfs)

A = 0.97716, where $A^{30}=0.5$. It represents the 30-day half-life.

The antecedent wetness is the watershed's wetness of the day prior to the onset of the storm.

¹ Two additional units in the North Fork Caspar Creek watershed were harvested during pretreatment. However, the peak flow model accounts for this harvesting.

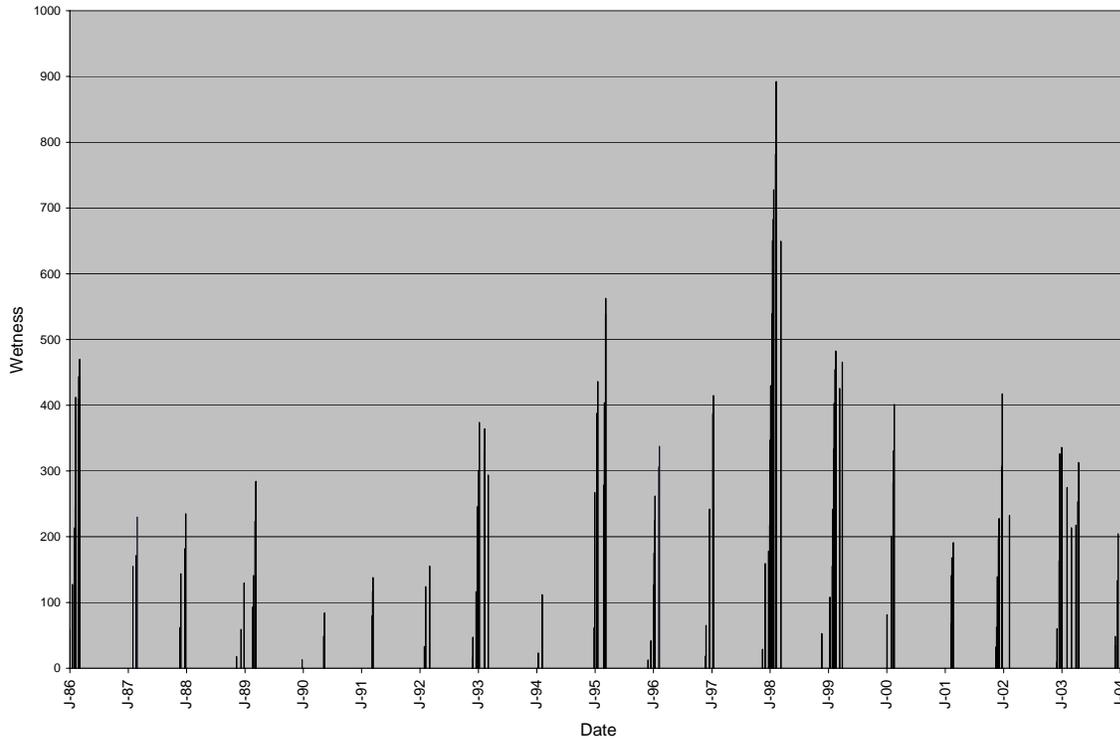


Figure 3. Antecedent wetness for storms used in the Caspar Creek peak flow model.

Staff analyzed the antecedent wetness data from hydrologic years (HY) 1986 through 2004. For the 19 years of data (see Appendix) the antecedent wetness ranged from 10 (dry conditions) to 892 (wet conditions). The antecedent wetness for storms that were used in the model are displayed in Figure 3. Note a large variability in the number of storms per year (2 to 14) as well as variability in wetness for each storm.

The distribution of antecedent wetness for the same time period is displayed as a boxplot in Figure 4. The bottom and top of the box present first (25th percentile) and third (75th percentile) quartiles, and contain within the box, the middle 50% of the values. The median (50th percentile) is marked by a line within the box and the mean is shown as an X. The whiskers extend to the values that fall within 1.5 * IQR (interquartile range). Outliers are plotted with asterisks (*) when they fall outside of this range.

The four outliers in Figure 4 represent four storms that occurred during the 1998 HY (Figure 3). It is interesting to note that 1998 had seven storms above the next largest wetness (563) that occurred outside of 1998 HY.

The median value is 224 while the mean value is 251. The first quartile is 116 while the upper quartile is 356. The distribution of the antecedent wetness is skewed to right (or “up” in the boxplot view).

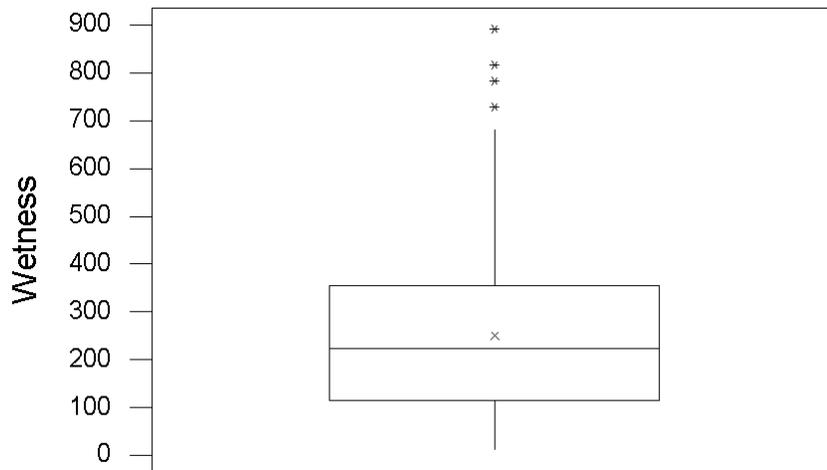


Figure 4. Boxplot of the antecedent wetness distribution.

Additional boxplots of the antecedent wetness are displayed in Figure 5 by hydrologic year and by the storm number for each year. The year to year variability in the wetness is apparent. It is interesting to note that for 17 of the 19 years of data, the mean is equal to or lower than the median. This result is expected because the low wetness values that occur in the beginning of the year lower the mean while the median is resistant to extreme values at the tails of the distribution. Increases in wetness by storm number also are apparent in Figure 5, with the wetness increasing throughout the winter period.

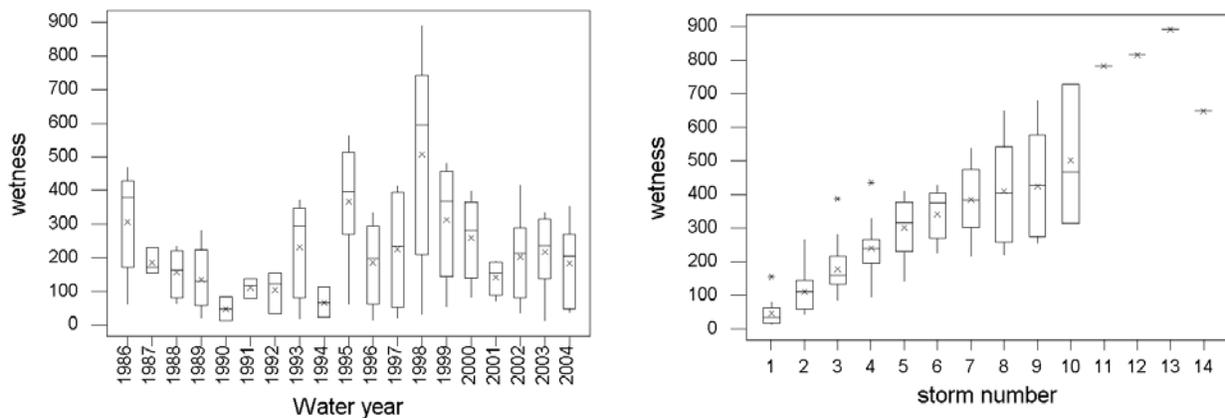


Figure 5. Boxplots of wetness by water year and by storm number for each year.

The peak flow model was developed from these storms and their associated antecedent wetness. No other variables related to roads, skid trails, landings, firelines, burning or herbicide application were found to improve the fit of the model (Lewis et al. 2001). The model for peak flow is mathematically represented by Equation 2 (PALCO, 2000) with the coefficients determined by the results of the experiment.

$$E(r) = \exp\{[1 + B_2(t - 1)]c[B_4 + B_5 \ln(y_c) + B_6 \ln(w)]\} \quad \text{Equation 2}$$

Where:

- $E(r)$ = expected ratio between the observed flow and the expected flow without a logging effect in a watershed as a result of a storm (unitless ratio)
 B_2 = logging recovery coefficient (-0.0771)
 B_4 = vegetation reduction constant (1.1030)
 B_5 = storm size coefficient (-0.0963)
 B_6 = watershed wetness coefficient (-0.2343)
 y_c = mean of unit area peak flows at control watersheds HEN and IVE ($\text{m}^3 \text{s}^{-1} \text{ha}^{-1}$)
 w = antecedent wetness (unitless parameter)
 c = proportion of watershed canopy removed (unitless ratio)
 t = time since harvest that calculation is made (years)

However, Lewis and Keppeler (in press) have refitted the model to all peak flows up to the time of the pre-commercial thinning. In doing so, the model's coefficients have changed slightly and are included in Table 1. The updated coefficients are used in all model runs in this report.

Table 1. Model coefficients for the peak flow model (Lewis and Keppeler, in press).

Parameter	Effect	Estimate
B_2	Recovery	-0.101
B_4	Vegetation reduction	1.290
B_5	Storm size interaction	-0.110
B_6	Wetness interaction	-0.278

To determine increases in peak flow due to canopy removal, appropriate values must be determined for: time since harvest (t), the portion of watershed canopy removed as a ratio of removed acreage to watershed acreage (c), antecedent wetness (w), and the mean of the unit area peak flows at the control watersheds (y_c). Staff did not use the fall logging coefficients from Lewis and Keppeler (in press) in the application of the peak flow model, because fall logging information was not available.

Time since harvest (t) is determined from a watershed's harvest history. The results from Casper Creek indicate recovery in 10 – 12 years (Lewis and Keppeler, in press). The portion of watershed canopy removed (c) is based on the harvest history for the watershed, with consideration of silvicultural method. This parameter is calculated simply as the clearcut equivalent acres harvested in that year divided by the watershed area. The harvest acres were converted to clearcut equivalents by applying a weighting coefficient that reflects the proportion of canopy removed per silvicultural method (see Appendix). Redwood Science Laboratory developed these coefficients. Regional Water Board staff has had further discussions with PALCO to ensure that the coefficients are the same as the coefficients used CDF's required application of the peak flow model in these watersheds. The coefficients are based on best professional judgment. Staff recognizes that there is considerable variability within silvicultural types in the amount of canopy removed, thus introducing some additional uncertainty into the application of the model. However, Regional Water Board staff feels that it is unnecessary to require the Discharger to monitor the amount of canopy removed per acre to reduce this uncertainty at this time.

Model sensitivity

It is important to understand the sensitivity of the Caspar Creek empirical peak flow model to changes in the input variables. By using the harvest history of North Fork Elk River, the sensitivity of the model's output to changes in the values of wetness and recurrence interval were evaluated.

It is important to look at the estimates of current conditions based on a range of values for both wetness and recurrence interval. As described earlier, wetness varies throughout the season. Results from the Caspar Creek experiment showed that all recurrence interval streamflows were affected by harvest-related increases.

Figure 6 demonstrates the effect that varying wetness has on estimation of peak flow increases in (a) 0.25-year, (b) 2-year, and (c) 15-year recurrence interval peak flows in North Fork Elk River. Recurrence intervals for the peak flow at the control watersheds (y_c) were determined from the partial duration series (Dunne and Leopold, 1978). While examining these figures, close attention should be paid to how the range of values for both wetness and recurrence interval affects the estimates for harvest related increases in peak flow. Figure 6(a) shows the flow increases for the minimum (10), first quartile (116), median (224), third quartile (356) and maximum (892) antecedent wetness. Figures 6(b) and 6(c) exclude the maximum wetness since it occurs outside of the range of observed values for these recurrence intervals and the model predicts negative values.

As shown in the figures, lower wetness generates higher increases in peak flow. Shorter recurrence interval storms (i.e. storms that occur more often) have higher increases in peak flows. These figures also show that the model is more sensitive to wetness than recurrence interval. The sensitivity of the model to wetness also can be deduced by noting that the coefficient for the wetness (B_6) is 2.5 times more than the coefficient for recurrence interval (B_5).

Another important factor to remember is that the peak flow model is an exponential model. The natural logarithm of the wetness and expected peak flow are used as inputs when determining the increase in peak flow (Figure 7). There are large differences in the result of the natural logarithm at the lower end of the scale, particularly when the wetness is lower than 150. This result matches the observed increases in peak flow quite well since the largest increases in peak flow occur when the wetness is lower (i.e., when the watershed is drier, canopy removal exerts a larger influence on runoff). A similar result occurs with the natural logarithm of the peak flow at the control watersheds (i.e., there are larger relative increases in peak flow for smaller storms than with larger storms).

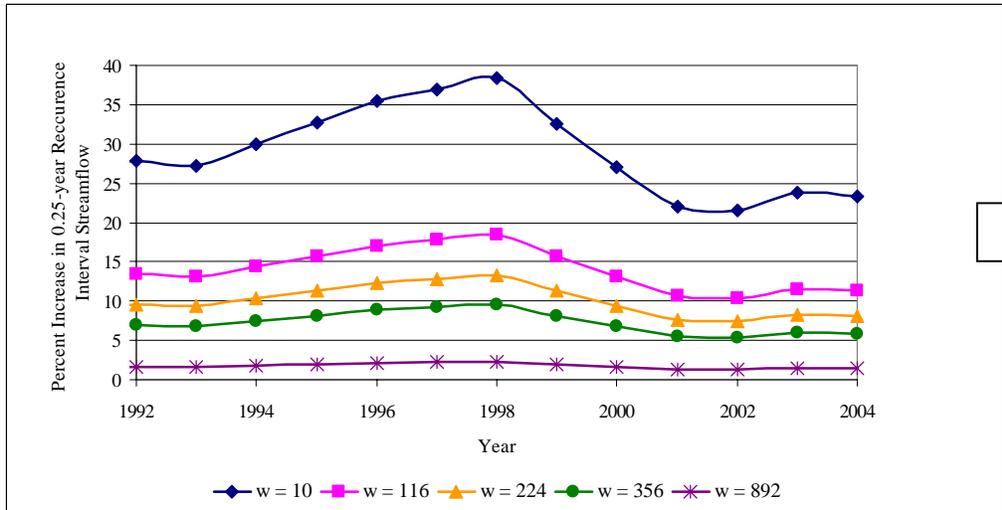


Figure 6a.

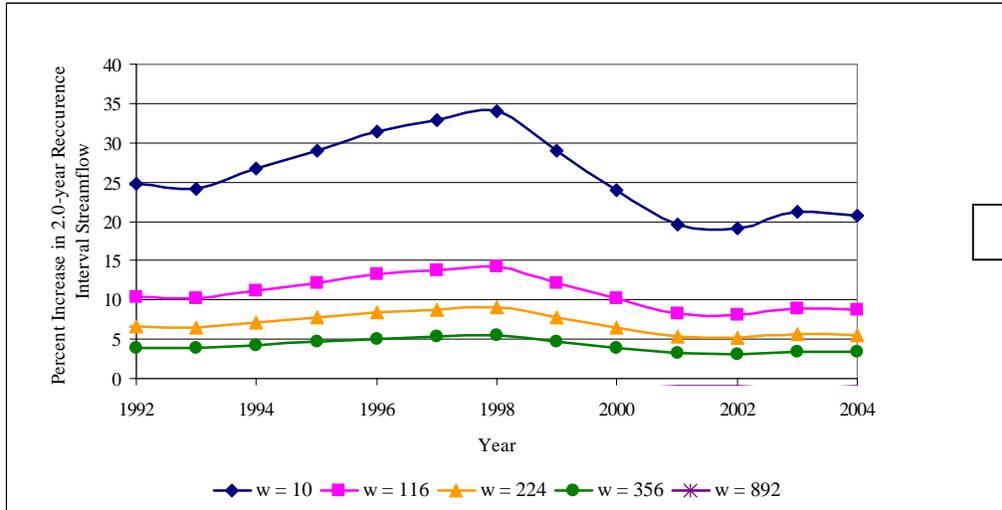


Figure 6b.

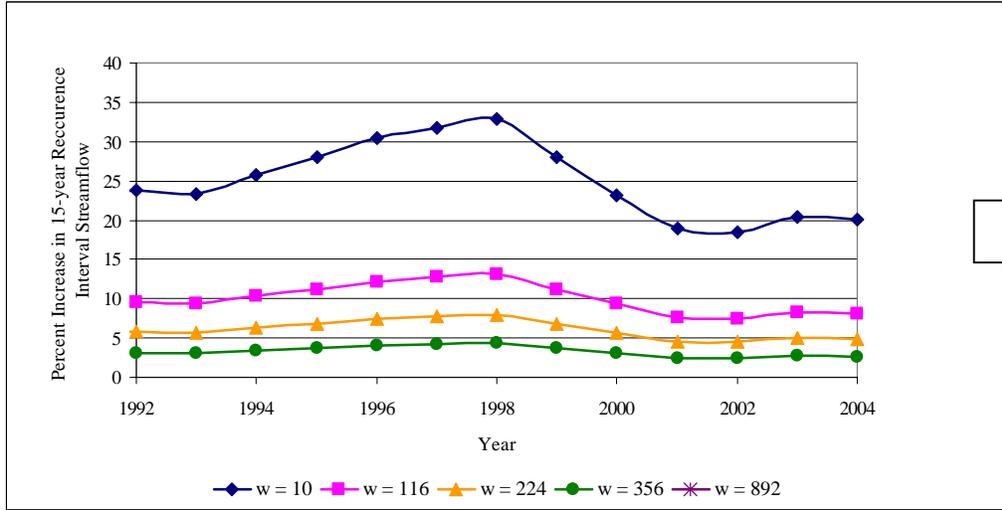


Figure 6c.

Figure 6. The percent increase in the a) 0.25-year, b) 2-year and c) 15-year recurrence interval stream flows for the minimum (10), first quartile (116), median (224), third quartile (356) and maximum wetness (892) for North Fork Elk River watershed and its recent harvest history. Figures 6b and 6c don't chart the maximum wetness since the model predicts negative values.

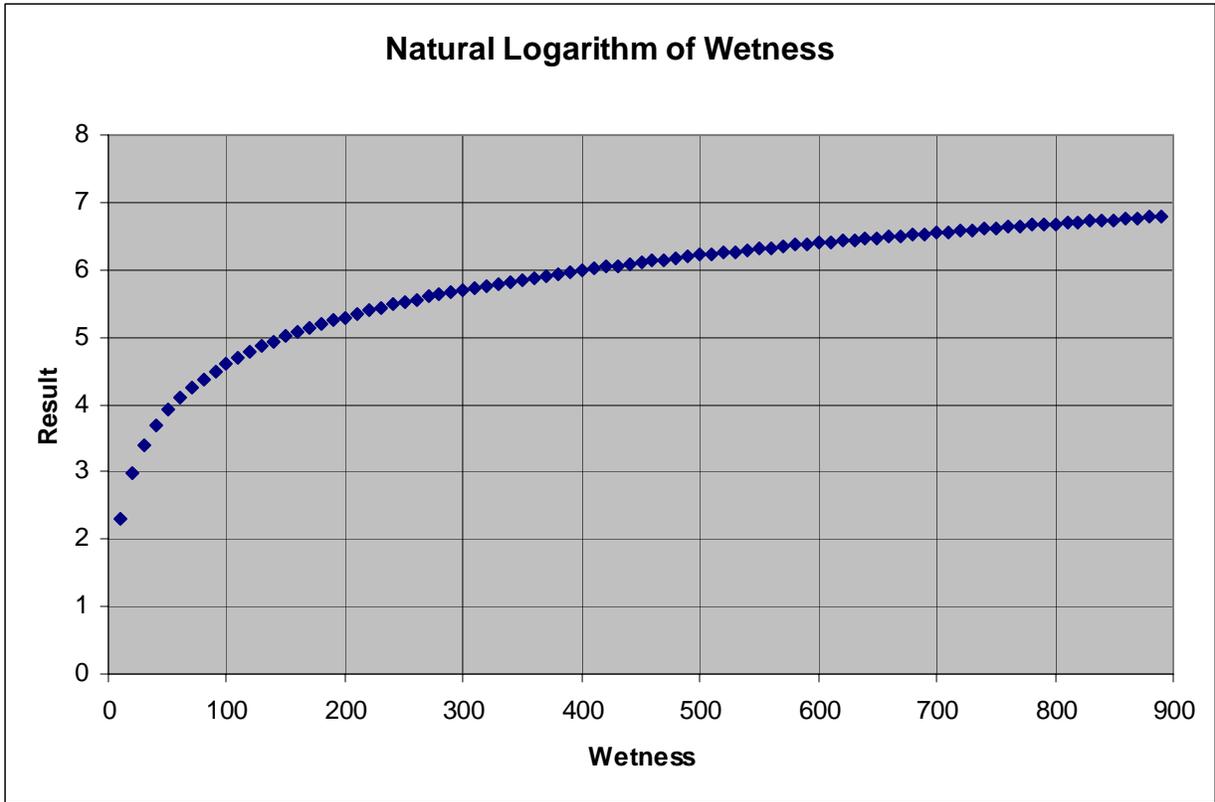


Figure 7. The natural logarithm of the wetness. The peak flow model uses the natural logarithm of wetness as an input into the model.

Table 2 summarizes estimated increases in peak flow in 2004 based on the harvest history in each of the subject watersheds.

Table 2. Summary of the 2004 increases in peaks flows.

Recurrence Interval	Wetness Index	Percent Increase in Peak flows		
		North Fork Elk River	South Fork Elk River	Freshwater Creek
0.25	10	23	9	25
	116	11	4	12
	224	8	3	9
	356	6	2	6
	892	1	1	2
2.0	10	21	8	23
	116	9	3	10
	224	6	2	6
	356	3	1	4
	892	*	*	*
15	10	20	8	22
	116	8	3	9
	224	5	2	5
	356	3	1	3
	892	*	*	*

* indicates that the values fall outside of the observed range

Model precision

Figure 8 shows the 95% confidence interval and the prediction interval for a 0.25 year recurrence interval storm that occurs with a watershed wetness of 150. The confidence interval predicts the mean response of the variable. The confidence interval approaches zero as the cut area goes to zero, because the form of the model ensures that the predicted change is zero regardless of the data or the coefficients (Lewis, 2005). The prediction interval is for an individual response and therefore is much larger than confidence interval (Devore, 1995).

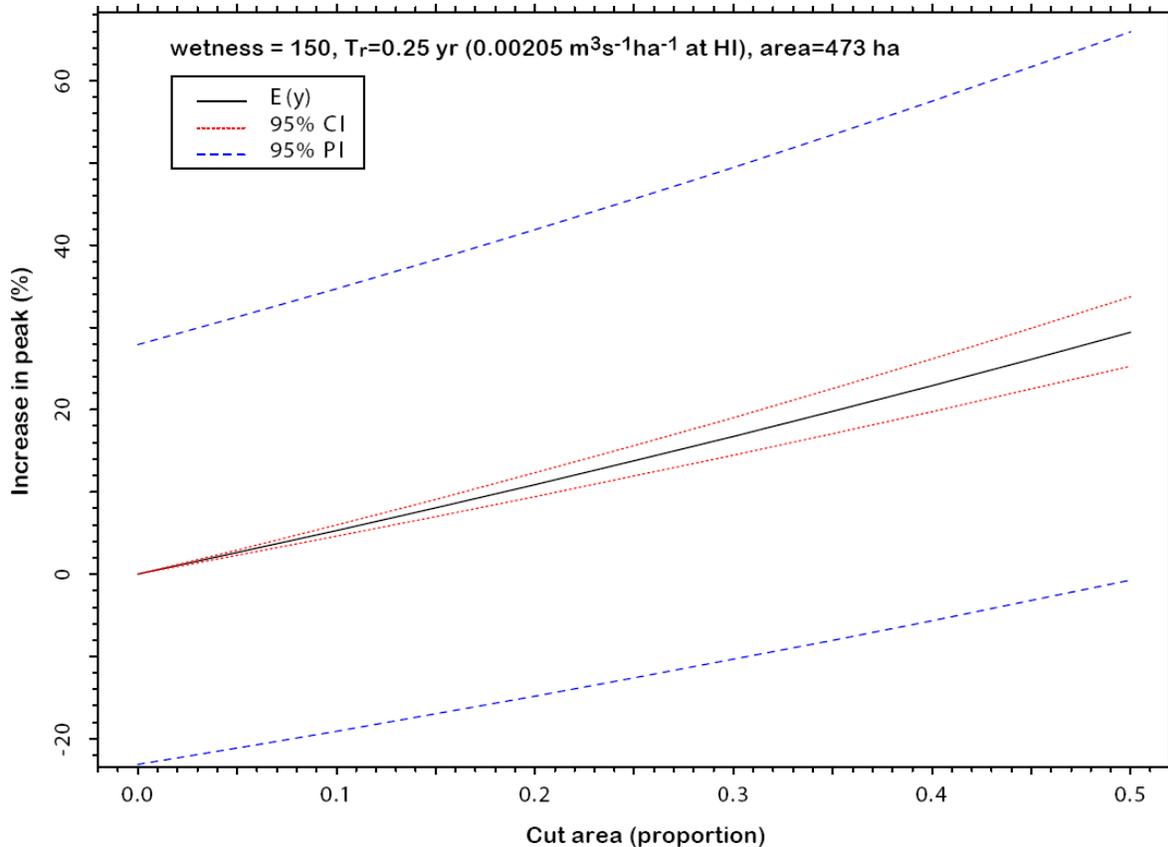


Figure 8. Confidence and prediction intervals for the North Fork Caspar Creek watershed (Lewis, 2005).

Application of Peak Flow Model to Freshwater Creek and Elk River

Watershed differences that may affect the results of the peak flow model

When applying the peak flow model to other watersheds, it is important to keep in mind that differences in the watersheds may cause the model to over-predict or under-predict peak flow increases. There are two major differences between Caspar Creek and the target watersheds that may affect the predictions of the model for the target watersheds.

First, the Freshwater Creek and Elk River are much larger watersheds than Caspar Creek. Freshwater Creek is approximately 19,700 acres while the largest of the monitored watersheds

on North Fork Caspar Creek is 1,170 acres; over sixteen times smaller. The differences in size will likely overestimate in peak flow increases.

The other major difference between Caspar Creek and the target watersheds are the extent and locations of roads and skid trails. The roads in Caspar Creek are all ridge roads that have no watercourse crossings. Caspar Creek had only 7.6% of the watershed harvested by tractors. The percent area in skid trails is 0.8%. This contrasts with the target watersheds, where there are numerous watercourse crossings, and where tractor harvesting has been conducted for over fifty years, which leaves a large network of skid trails in the watershed. Hence, there are large differences in effective watercourse network and compaction in the watershed which will likely underestimate in peak flow increases.

For purposes of calculating increases in peak flow for the target watersheds, Regional Water Board staff has assumed that the overestimation due to watershed size is offset by underestimation due to roads and skid trails. It is difficult to assess the veracity of this assumption. A rough estimate of the effect of watershed size is that it overestimates the peak flow effect by 25% (Megahan 2005) although there are more sophisticated approaches (such as HEC-HMS modeling or developing synthetic unit hydrographs) that should have greater accuracy in estimating this effect (Liquori 2005). On the other hand, increases in peak flow due to roads is more difficult to estimate. Jones and Grant (1996) found that increases due to harvesting and roads produced much greater changes in peak flow than either clear-cutting or roads alone in small basins and suggested the same effect exists for large basins (these large basins had average harvest rates of less than 1% and relatively low road densities of approximately 2 to 3 km km⁻²). It should be noted, however, that Thomas and Megahan (1998) disagree with this conclusion because of the lack of statistical evidence. Jones (2000) found that in small basins, that roads increased peak flows from 13 to 36% for storms greater than the 1-year return period and concluded that mid-slope roads had the greatest effect on peak flows. LaMarch and Lettenmaier (2000) used a physically based hydrologic model to estimate that roads (approximately 3.7 km km⁻²) in large basins increased peak flows 2.9 to 9.5% for the 1-year storm event. An additional consideration is that the above studies in Oregon and Washington do not incorporate the effects of skid trails, as tractor yarding is much less prevalent than it is in California. The HCP requires road stormproofing, which encourages the hydrologic disconnection of inside road ditches and the outloping of roads, which should lower the impacts of roads on peak flows. Therefore, considering the above information, we find that the assumption of basin size being counteracted by roads and skid trails to be slightly conservative but reasonable.

Also, there are minor differences between the watersheds. Clearcuts in Caspar Creek “cleaned” and four of the eight units harvested between 1989 and 1991 were broadcast burned. The units underwent pre-commercial thinning, which caused a renewed response in peak flow increases (Lewis and Keppeler, in press). Clearcuts in Freshwater Creek and Elk River don’t experience the same amount of vegetation removal or broadcast burning as the Caspar Creek clearcuts and PALCO essentially stopped the practice of pre-commercial thinning in 1999 in these watersheds (Horner, 2005). Therefore there may be differences between Caspar Creek and the target watersheds in the initial peak flow response and recovery rates; however, Regional Water Board

staff believe that these differences will have very small effects on the peak flow model, even if they are present.

Procedure for model application

Several steps were taken to apply peak flow model to the Freshwater Creek and Elk River watersheds. Appropriate input parameters for the Caspar Creek empirical peak flow model were determined before the selection of targets. This included determining (1) the watershed area and harvest history, (2) peak flows (y_c) and recurrence interval, and (3) wetness.

Watershed area and harvest history

The geographic extents of the analyses are defined based upon a combination of factors, including watershed size, ownership, and land use, and location of nuisance flooding conditions. Staff determined that the appropriate watersheds in which to use the peak flow model are the Freshwater Creek, North Fork Elk River, and South Fork Elk River watersheds. Staff chose these watersheds because the harvest histories were available, but also because there is specific information allowing the calculation of the appropriate recurrence interval for nuisance conditions.

The North Fork and South Fork Elk River were evaluated separately, because 1) the model was developed from smaller watersheds, and 2) applying the model to the North Fork and South Fork separately acknowledges the differences in timber harvest intensity and land use (i.e., the large forested tract of the Headwaters Forest Reserve in the South Fork Elk River watershed). The WWDRs apply to lands in the upper three Freshwater Creek planning watersheds. The Howard Heights Bridge is the location chosen for defining nuisance. It is assumed that the recurrence interval of nuisance at the downstream extent of the three planning watersheds is comparable to that of Howard Heights.

When applying the peak flow model, staff considered three different options of watershed area and PALCO's harvest history for determining the portion of canopy removal (c). The options are: total watershed area and total harvest history, total watershed area and PALCO's harvest history, or PALCO's ownership and harvest history. While the two latter options may have advantages because the permit will only apply to PALCO, staff determined that using the total watershed area and harvest history is appropriate for this permit even though it underestimates the effect of canopy removal on PALCO's ownership. This option was chosen, because the estimated increases in peak flow could then be transformed to show increases in the flood stage height. The ability to convert percent increases in peak flow into stage height helps to determine an appropriate target for increases in peak flow. Examination of the harvest histories shows that other landowners have had minor amounts of timber harvest. It is anticipated that future canopy removal from other landowners will also be minor. When future timber harvest plans by other landowners are received, staff will consider if the General WDRs are appropriate.

Harvest histories were provided by PALCO (2004a and 2004b), Green Diamond Resource Company (2004), and CDF. The harvest histories consist of summaries of acreage under different silvicultural applications applied across the watershed landscape. Different silvicultural treatments use coefficients described in the Appendix to transform the number of acres into

clearcut equivalent acres. For purposes of the rest of this discussion, the term “North Fork Elk River” refers to all areas in the Upper and Lower North Fork Elk River planning watersheds and “South Fork Elk River” refers to all areas in the Upper and Lower South Fork Elk River planning watersheds minus Railroad² Gulch. “Freshwater Creek” refers to all areas in Cloney Gulch, Little Freshwater, and Upper Freshwater Creek planning watersheds.

Peak flows (y_c) and the recurrence interval

As described above, the peak flow model estimates the percent increase in a specified peak flow. The partial duration series (Dunne and Leopold, 1978) is used to transform the peak flows at Caspar Creek into recurrence intervals. To apply the peak flow model for the Freshwater Creek and Elk River watersheds, the recurrence intervals for Caspar Creek are matched with the recurrence intervals for nuisance flooding. The target recurrence interval streamflow is the peak flow associated with nuisance flooding for the current conditions in the Freshwater Creek and Elk River watersheds. Nuisance flooding occurs at different recurrence intervals for locations where the model is applied.

The partial duration flood series is also useful for estimating stream flow and precipitation events of low recurrence interval from a short record. The partial duration series includes all flood peaks above a certain base magnitude. The base is usually chosen as equal to the lowest annual maximum flood of record. However, because we are interested in determining the lowest recurrence interval of stream flows resulting in nuisance conditions, we evaluated the partial duration series for stream flows in which specific locations are inundated as our base. It should be noted that when using the partial duration series, that peaks should be independent of one another (Dunne and Leopold, 1978). To satisfy this requirement, we used the same methodology as Lewis et al. (2001) and didn’t include peaks that occurred within 24 hours of one another and, when the data were available, where the discharge didn’t drop by at least 50% in the intervening period.

The recurrence interval based on the partial duration series was calculated per Equation 3.

$$RI = (n+1) / m \qquad \text{Equation 3}$$

Where,

- RI = recurrence interval of peak flow
- n = number of years in record
- m = rank of peak flow in record

Appropriate target recurrence intervals of peak flow events were evaluated. Peak flows that result in nuisance conditions to people were identified by:

1. identifying locations where nuisance occurs when area is inundated,
2. identifying the stage and associated discharge above which the identified location is inundated, and

² Railroad Gulch is tributary to Mainstem Elk River, not South Fork Elk River, as the CALWATER watershed maps suggest. Consequently, for purposes of this analysis and the WWDRs, Railroad Gulch (~742 acres) is not considered part of South Fork Elk River.

3. evaluating available records to determine the recurrence interval of the stage and streamflow to inundate the location.

Once the recurrence interval for the nuisance flood event in the watershed is determined, the recurrence interval is used as a surrogate for the control peak flow (y_c).

Freshwater Creek

The Howard Heights Bridge over Freshwater Creek on Howard Heights Road was chosen as the location for the application of the peak flow model because the nuisance flooding there is quite apparent and its frequency is quantifiable. The flooded section of road adjacent to the bridge limits residents' ingress and egress. Of particular use to the determination of recurrence intervals of nuisance flows is a record of dates for which the river floods at the bridge.

To determine the frequency of flooding at the Howard Heights Bridge, staff solicited records maintained by the residents of Howard Heights Road (Cook). In addition to the declaration, dates were reported to complete Hydrologic Year 2004 (Cook, 2004 & 2005).

Table 3. Summary of flood events at Howard Heights Road bridge.

Hydrologic Year					
1999	2000	2001	2002	2003	2004
11/21	1/11		12/5	12/14 & 15 & 16	12/13 & 14
11/23	1/14		12/13 & 14	12/27 & 28	1/1
12/2	2/14			12/31	2/17 & 18
2/6 & 7				2/19	
3/24				3/26	
				4/25	

From those data, the recurrence interval of flooding was calculated as 0.37 (2.7 times per year), with $n = 6$ and $m = 19$. For application in the Freshwater Creek watershed, the design recurrence interval stream flow was designated as: $RI = 0.4$.

The basic assumptions to this calculation are:

- 1) The recurrence interval of nuisance at Howard Heights is similar to that of the bottom of the drainage area of the three planning watersheds. Howard Heights Bridge comprises 84% of the drainage area.
- 2) The record of the observed floods as submitted by the Cooks are complete and include all floods during the evaluated time period.
- 3) Floods occurring on sequential days were considered a single event. This assumption likely underestimated the total number of events, and likely yielded a higher (less frequent) recurrence interval for flooding of Howard Heights Bridge than actually occurs.

North Fork Elk River

A key location affecting access and egress for residents of both North Fork and South Fork Elk River is immediately downstream of the North Fork Elk River Bridge and the intersection of Elk River Road and Wrigley Road.

Watershed Watch, a local volunteer watershed group, installed water level staff plates and began stream flow measurements in the North Fork Elk River in HY 2000. Both Watershed Watch and PALCO began continuous stage monitoring in North Fork Elk River in HY 2003. Stage-discharge relationships allow the stage (water level) to be converted into a continuous discharge³ (stream flow) record, or hydrograph. The stage-discharge relationship developed by Watershed Watch for monitoring stations NFE (discharge measurements are made at Station NFE, located at the North Fork Elk River Bridge) and KRW (electronic stage measurements are made at Station KRW, located at 2550 Wrigley Rd) is displayed in Figure 9. The hydrographs for HYs 2003 and 2004 are displayed in Figure 9. These discharge records were used to determine the frequency, or recurrence interval of nuisance flooding through the partial duration series.

Regional Water Board staff conducted field surveys to determine the elevation of various points along the roadway to estimate the corresponding discharge that results in inundation of the roadway. The surveys was conducted from the south of the Elk River Road concrete bridge downstream to a small watercourse that enters North Fork Elk River along the right bank. The field survey and calculations are included in the Appendix.

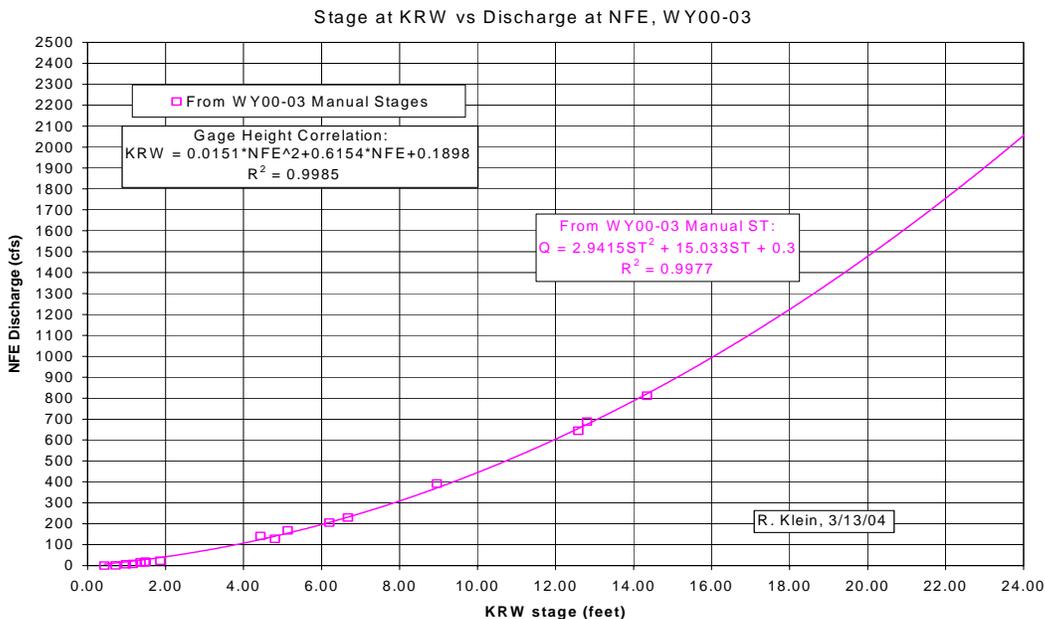


Figure 9. Watershed Watch stage-discharge relationship and rating curve for KRW station in the North Fork Elk River watershed.

³ The use of “discharge” is conventional in scientific discussions and is synonymous with stream flow rate. Its use in this report is in that context, and should not be confused with the use of the term “discharge” in a regulatory sense.

A culvert meant to drain the road surface along the river side of the road is inundated at a discharge of 466 cubic feet per second (cfs), becoming completely ineffective. A berm separates the road from the river, and a break in that berm is the first place water enters the road area (at 484 cfs) and reaches the river-side edge of the pavement (at 508 cfs.) At 588 cfs, water reaches the centerline of the roadway for a distance of approximately 35 feet. At 640 cfs, a 240-foot length of road is entirely covered with water depths up to 2 feet.

The hydrographs shown in Figure 10 indicate the number of storm events that reached the center of the pavement (flows greater than 588 cfs) for HY 2003 and 2004. The largest peaks in a 24-hour period greater than 588 were considered flooding events.

During HYs 2003 and 2004 ($n = 2$), twelve peaks meeting the criteria were identified ($m = 12$). The calculated recurrence interval of peak flow reaching the center of the pavement is 0.25 years (i.e., occurs 4.0 times per year) and was selected as the target recurrence interval associated nuisance flooding.

The primary limitation to this estimate is that only two years of data were available and therefore there is a large amount of uncertainty associated with the estimated nuisance recurrence interval. The recurrence interval may change as additional years of data become available.

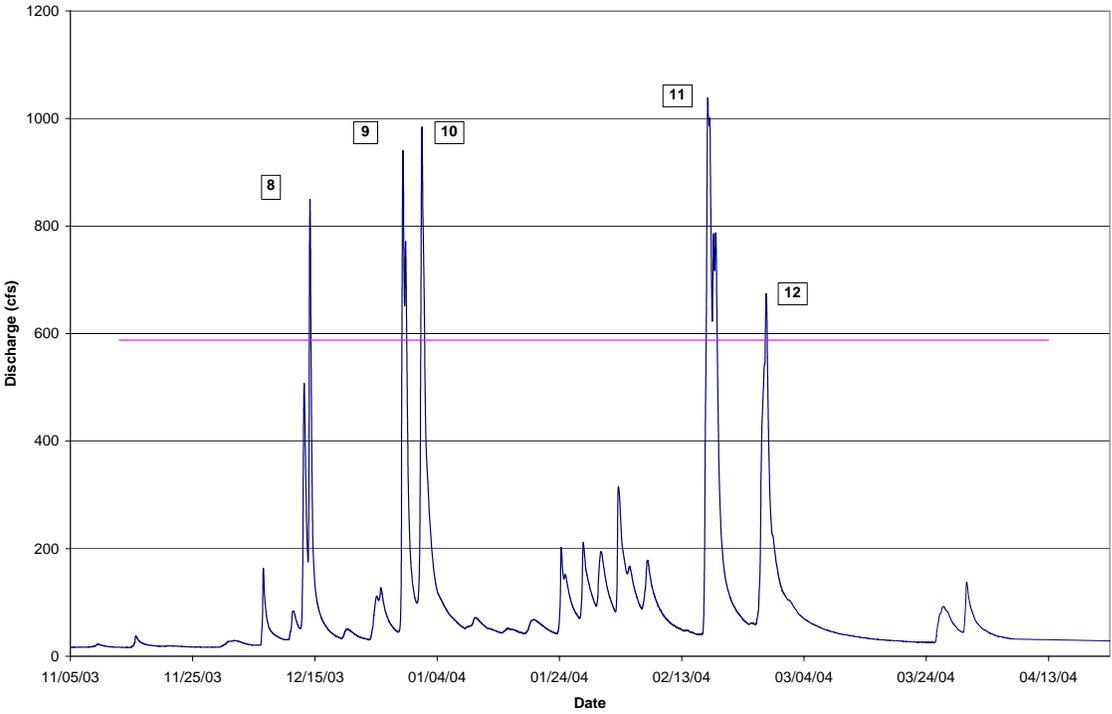
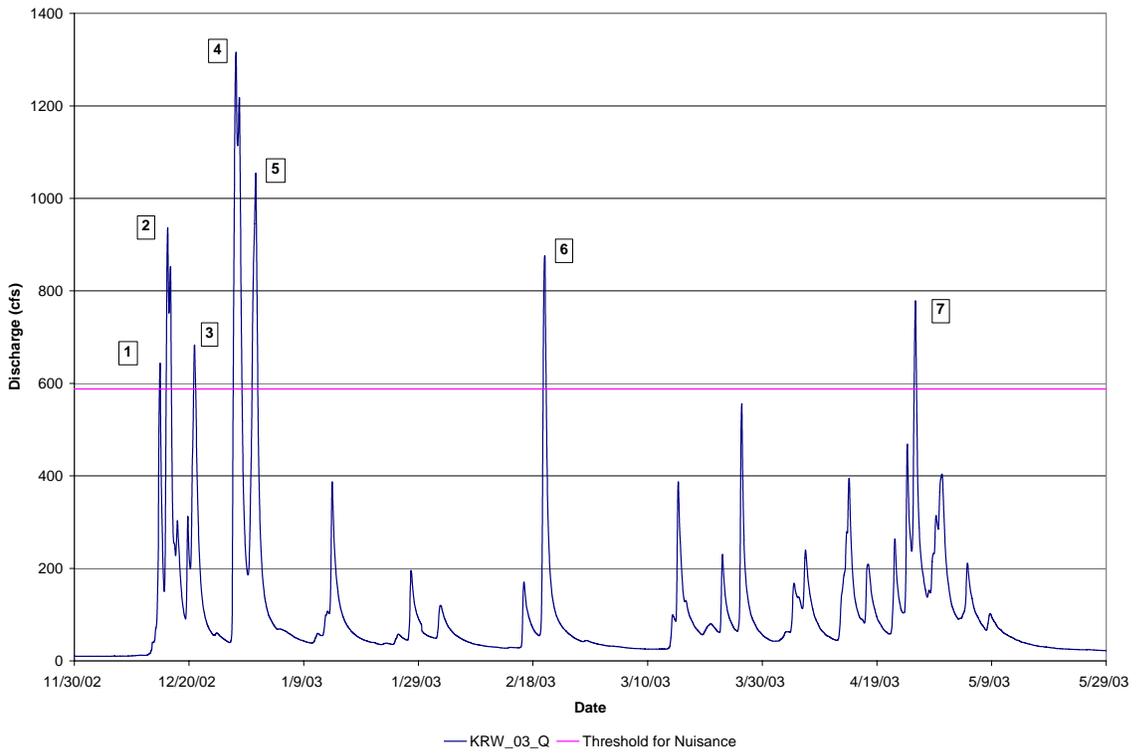


Figure 10. Hydrographs for the North Fork Elk River for hydrologic year 2003 & 2004. Storms with peak flows that exceed the threshold are numbered.

South Fork Elk River

Nuisance at South Fork Elk River is not as well documented as on the North Fork Elk River. Staff has received complaints of channel filling, inundation of orchards and driveways, overtopping of recently retrofitted bridge deck, and water inundating the crawl space beneath homes and threatening to enter homes.

Watershed Watch installed staff plates and in HY 2001 began stream discharge measurements at 8050 Elk River Road (located on lower South Fork Elk River); they installed a continuous stage recorder in HY 2003.

Staff conducted a survey at 8050 Elk River Road to determine the elevation of various features, including the driveway, the floor levels of the existing buildings, and the level of concrete slabs which can cause damage to property when inundated. These elevations were tied into the stage-discharge relationship to determine the discharge required for inundation. The contemporary stage-discharge relationship is shown in Figure 11 below. Based upon the survey and the stage-discharge relationship, we determined that a discharge of 1,338 cfs results in access limitations at the residence surveyed on South Fork Elk River. However, only a single peak achieved this stream flow during the period of record for the HY 2003 and HY 2004 discharge records. This indicates that the nuisance event may occur at the same recurrence interval as bankfull events (events that occur every 1.5 to 2 years).

The short period of record limits the ability to estimate the frequency of nuisance flooding. Furthermore, staff only surveyed one residence and there may be another location where nuisance occurs at a lower stage height. Therefore, since nuisance flooding does not appear to be an issue in the South Fork Elk River watershed, we recommend continued monitoring of the watershed. If the monitoring results shows that nuisance flooding does become a problem, adaptive management should be used to incorporate peak flow modeling into the permit.

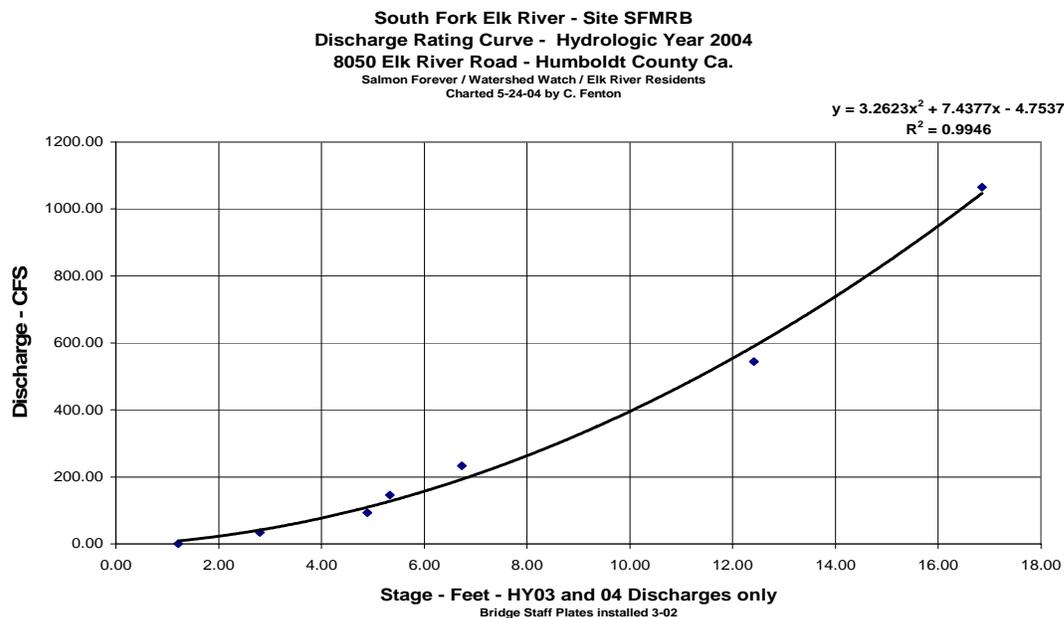


Figure 11. Watershed Watch’s stage-discharge relationship and rating curve for South Fork Elk River.

Wetness Distribution

To help determine an appropriate antecedent wetness, we used the Monte Carlo approach to produce a random wetness distribution based on the Caspar Creek data, and to produce exceedance probability curves (PALCO, 2005a). However, some slight changes were made to PALCO's methodology.

First, we used the full dataset of antecedent wetness instead of discarding a portion of the distribution. PALCO (2005c) recommends discarding wetness values that occurred for storms with recurrence intervals less than the estimated nuisance recurrence interval (0.25 years for North Fork Elk River, 0.40 for Freshwater Creek). However, there are more meaningful ways to select a portion the antecedent wetness distribution. One approach is to remove the outliers of the observed wetness distribution (Figure 3). Another approach is to discard wetness values that are associated with storms that are larger than bankfull discharge (1.5 – 2.0 years), since these events overtop the stream banks and cause flooding in undisturbed watersheds.

Lisle, et al. (2000b) evaluated a wetness distribution with recurrence interval greater than 0.25 years when they conducted their analysis for the 2-year recurrence interval flow. CDF (Munn 2001, 2002) used the same dataset as Lisle, et al., for their analysis. It also should be noted that there is a poor, but significant relationship between wetness and storm size for the full range of storms, but for storms greater than 0.25-year recurrence interval there is not a significant relationship between wetness and storm size.

Staff evaluated all these scenarios, which in effect would increase or decrease the median and mean of the distribution. A significant concern is that there is a limited amount of flow data in these watersheds at the nuisance locations to determine the nuisance recurrence interval. Furthermore, we believe it is important to use the model for current conditions in the watersheds where nuisance flooding is occurring for small storm events (e.g. 0.25 and 0.4-year recurrence interval events). Therefore, given this uncertainty, we find it reasonable to include the full dataset when conducting the analysis. By using the full dataset, a few storms that are not contributing to nuisance flooding will be included in the analysis, but this will be offset by large storms that would not be contained within the stream banks under natural conditions. Also, since the nuisance recurrence interval used in this analysis is much smaller than the recurrence interval used in previous efforts (Lisle, et al. 2000b and Munn 2001, 2002), it is appropriate to use the full distribution of antecedent wetness even though a portion of the distribution occurs at recurrence intervals less than the target interval.

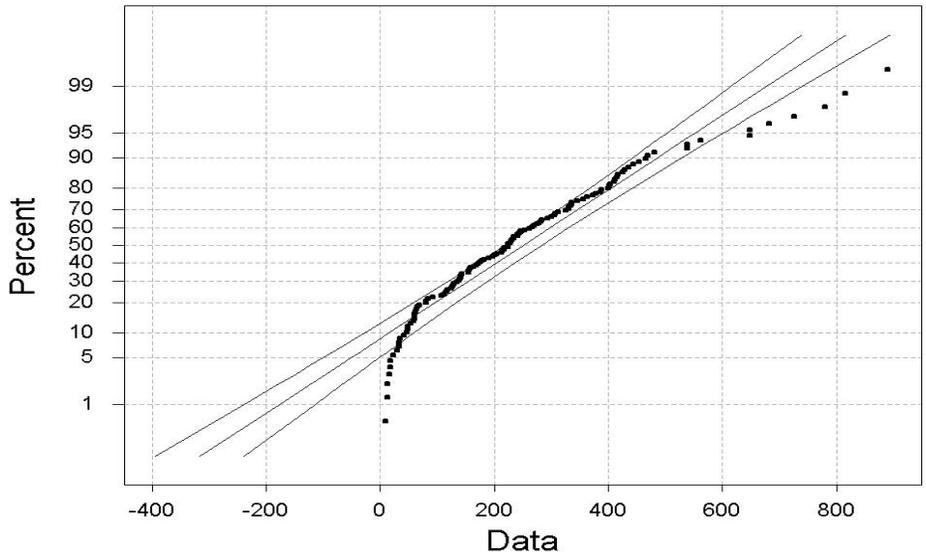
Second, when producing a random distribution, PALCO (2005c) recommends using a normal distribution for the wetness distribution. We chose to use the Weibull distribution for several reasons, including the fact that observed wetness distribution is not normal, but skewed to the right. There are several physical reasons for this. First, the wetness index is based on accumulations of daily mean flow. Daily mean flow is not normally distributed, therefore there is little reason to suspect that the wetness index is normally distributed. Second, the wetness index is bounded by zero (there can be no negative values) at the lower end of the distribution. Normal distributions have a non-zero probability for all values (i.e., they are unbounded).

We used the adjusted Anderson-Darling statistic from MINITAB® statistical software to determine the goodness-of-fit for several distributions for both maximum likelihood and the least squares methods. The observed antecedent wetness was compared to normal, lognormal, Weibull, and other distributions. The Weibull distribution had the lowest Anderson-Darling statistic (0.486 compared with 2.161 for normal distribution and 2.731 for lognormal distribution), indicating that the Weibull distribution is the best fit. Probability plots were produced using MINITAB® and are shown in Figure 12 for the normal distribution and the Weibull distribution. As shown in the figure, the Weibull distribution not only fits the data better in the tails of the distribution and only has one data point outside the 95% confidence intervals, but also is closer to the fitted line than the normal distribution.

Normality tests were conducted for the antecedent wetness using both the Kolmogorov-Smirnov test and the Anderson-Darling test. The P-values were < 0.01 and 0.000 respectively, which indicates the null hypothesis (the data follow a normal distribution) is rejected (i.e., the observed antecedent wetness distribution is not normally distributed).

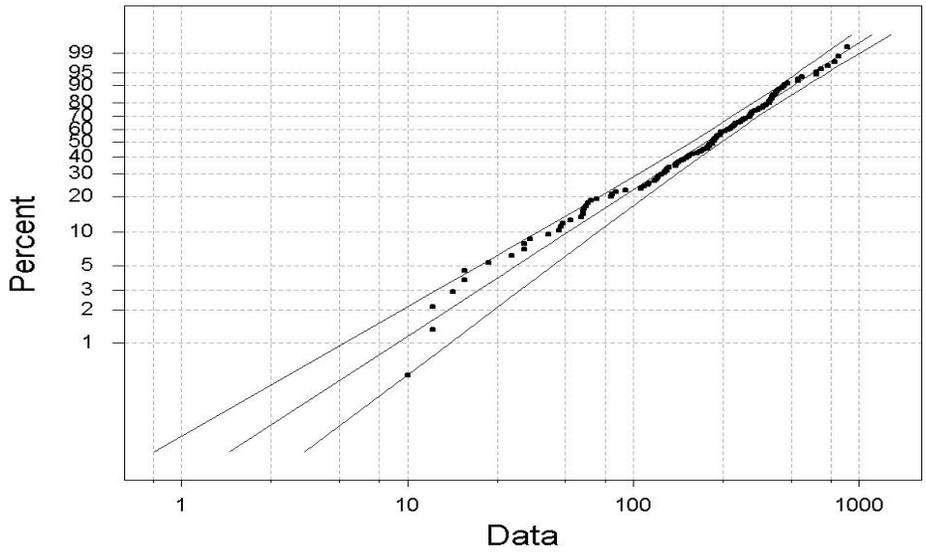
It is important to note that if a normal distribution was used, it would significantly underestimate the frequency of observed antecedent wetness values in the lower end of the distribution. This has a significant affect on the peak flow model's distribution and it will under-predict increases in peak flow. (The exceedance probability chart for both the normal distribution and the Weibull distribution is shown in Figure 13.) Therefore, for these reasons, we used a Weibull distribution when we generated a random wetness distribution for the Monte Carlo simulation.

Normal Probability Plot for Wetness
ML Estimates - 95% CI



ML Estimates
Mean 250.715
StDev 183.718
Goodness of Fit
AD* 2.161

Weibull Probability Plot for Wetness
ML Estimates - 95% CI



ML Estimates
Shape 1.34872
Scale 272.920
Goodness of Fit
AD* 0.486

Figure 12. Probability plots for the observed antecedent wetness distribution.

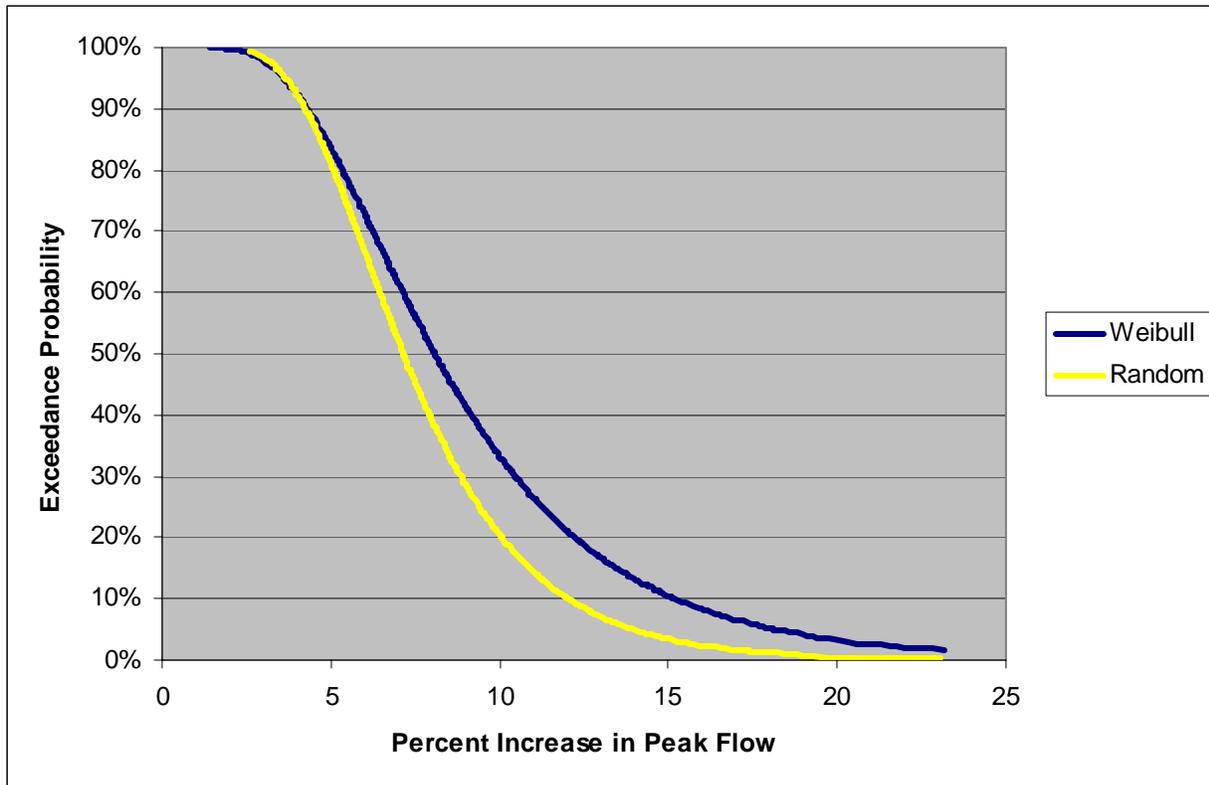


Figure 13. Exceedance probability for predicted increases in peak flow for North Fork Elk River.

Margin of safety

In order to determine an appropriate margin of safety for the application of the peak flow model in these watersheds, we take guidance from the Clean Water Act. Clean Water Act section 303(d)(C) states “Such load shall be established at a level necessary to implement the applicable water quality standards with seasonal variations and a margin of safety which takes into account any lack of knowledge concerning the relationship between effluent limitations and water quality.” The Total Maximum Daily Load (TMDL) regulations mirror this language, and state “determinations of TMDLs shall take into account critical conditions for stream flow, loading and water quality parameters.” (40 CFR §130.7 (c)(1)).

Regional Water Board staff has determined that it is appropriate to define critical conditions as the winter period since flooding occurs throughout this period. For the margin of safety, a close examination of the exceedance probability chart (Figure 13) is key to determining an appropriate margin of safety. It is helpful to think of exceedance probability in terms of risk; a particular increase in peak flow has an associated amount of risk (i.e. chance of happening). For example, a 15% increase in peak flow has a 10% percent chance of occurring. An event that occurs half (50%) of the time may seem like an appropriate starting point; however, a key consideration is the shape of the exceedance probability curve and the fact that the curve is skewed to the right. The average increase in peak flow is 9.1% and has an exceedance probability of 41%. Therefore, a margin of safety should be lower than 41%. The following factors were considered when determining the margin of safety: the protection of beneficial uses of water; water quality standards and reduction of nuisance conditions; the current conditions of the watershed; the likelihood of natural recovery and the timeframe for that recovery; the likelihood of assisted

recovery or infrastructure improvements and the timeframe for them to be implemented; and economic impacts on the discharger and affected residents in the watershed.

Staff recommends that an exceedance probability of 33% is an appropriate value for this permit, which includes a margin of safety and accounts for the current conditions of the watershed. In essence, the exceedance probability of 33% means that one out of three times there is a likelihood of under-predicting increases in peak flow. The corresponding antecedent wetness for this exceedance probability is 150 and represents a 10% increase in peak flows for North Fork Elk River for 2004.

Selection of Targets for Application of the Peak Flow Model

To apply the peak flow model to these watersheds and to reduce some of the current nuisance conditions, two additional targets must be determined: the allowable percent increase in peak flows, and the timeframe to reach that goal. To help determine these targets, several canopy removal scenarios were evaluated, including the most rapid (no harvest), 10-years, and 20-years for the three watersheds for the recurrence interval (0.4, 0.25, and 1.5 for Freshwater Creek, North Fork Elk River and South Fork Elk River respectively) with antecedent wetness of 150. These scenarios are shown in Figures 14 and 15. For Elk River, the charts show a proportional split of CDF's harvest limit among North Fork, South Fork, and the main stem of Elk River.

We recommend an allowable increase in peak flow of 5% to allow some recovery from the nuisance conditions in the Freshwater Creek and North Fork Elk River watersheds for the current conditions of the watershed (i.e. for the 0.4 and 0.25-year recurrence interval storms respectively). Furthermore, we recommend a ten year time frame to reach the 5% allowable increase. Similar to the margin of safety, the following factors were considered in setting the allowable increase and time frame: the protection of beneficial uses of water; water quality standards and reduction of nuisance conditions; the current conditions of the watershed; the likelihood of natural recovery and the timeframe for that recovery; the likelihood of assisted recovery or channel improvements and the timeframe for them to be implemented; and economic impacts on the discharger and affected residents in the watershed.

For North Fork Elk River, if nuisance were considered at 588 cfs (where one lane is blocked by floodwaters), the current estimated peak flow increase of 10% (at a wetness of 150) would be reduced by approximately 30 cfs, which would lower the floodwaters by approximately three inches. Since the probability of this increase in peak flows is 33%, potentially a third of the time the decrease in peak flow would be more than this amount when the 5% target is reached.

For Freshwater Creek, a ten-year trajectory to meet this target would allow 271 acres of clearcut canopy removal per year. For North Fork Elk River, a ten-year time period would allow 187 acres of clearcut canopy removal per year. Figure 14 also shows that a "no harvest" scenario would allow the 5% target to be reached in three years.

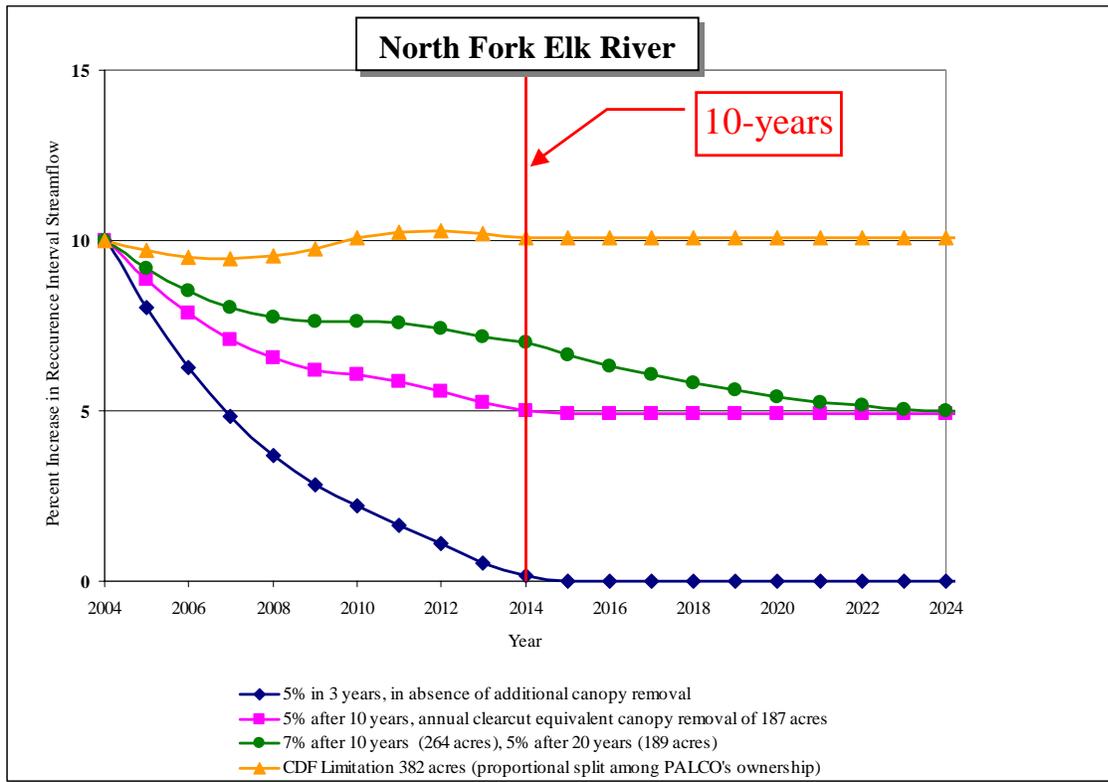
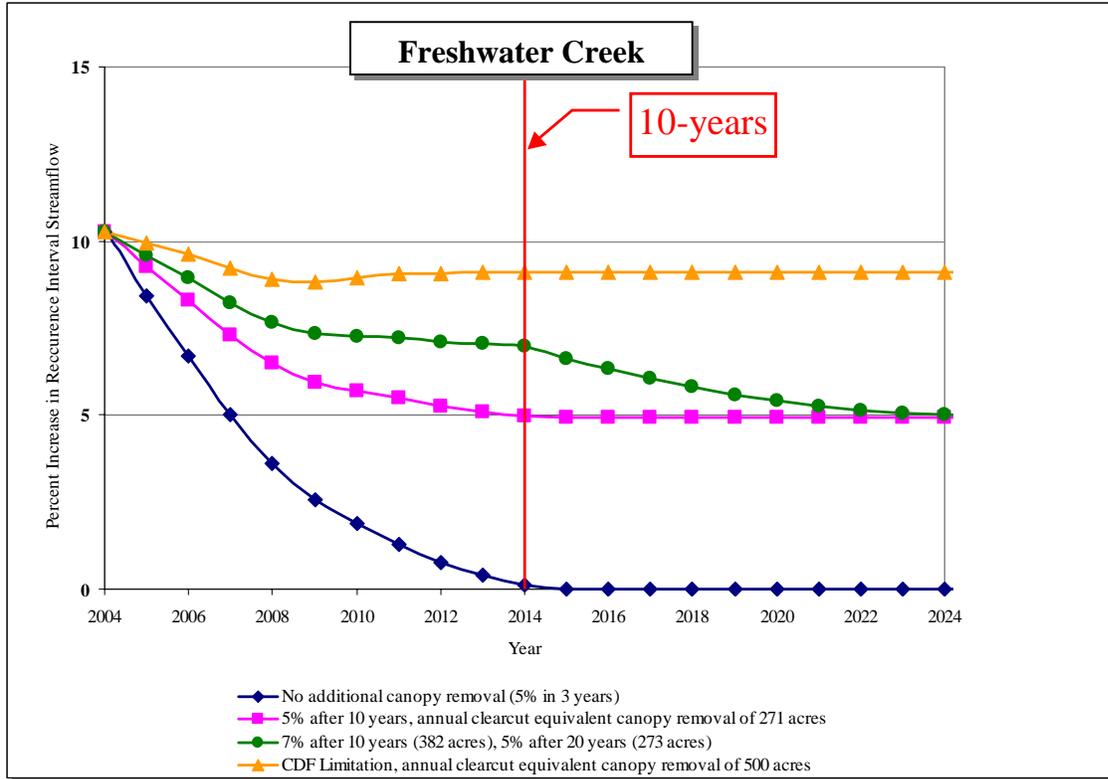


Figure 14. Peak flow increases over the next 20 years based on a variety of future canopy removal scenarios for Freshwater Creek, and North Fork Elk River.

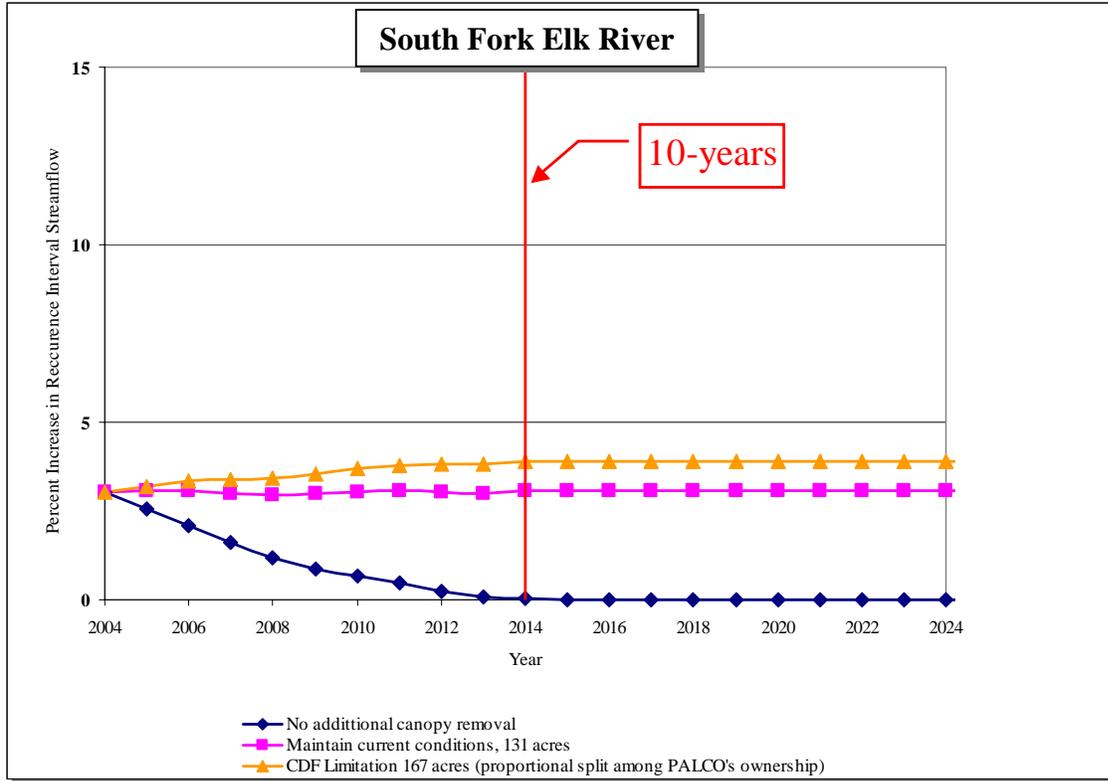


Figure 15. Peak flow increases over the next 20 years based on a variety of future canopy removal scenarios for South Fork Elk River.

Figure 15 shows that the target level for South Fork Elk River is already below 5%. Since the 5% target is already met and it that nuisance flooding is not an issue in this watershed, we recommend continued monitoring of the watershed. If monitoring results shows that nuisance flooding does become a problem, adaptive management should be used to incorporate peak flow modeling into the permit.

Table 4 shows how canopy removal rates adjust for different levels of exceedance probability for the 5% allowable increase target and the ten-year time frame. Figure 16 shows the same information, with the highlighted red point being 33% exceedance probability selected by Regional Water Board staff as the recommended value for use in this permit. It is important to remember that the average increase in peak flow occurs at 41% and therefore it would not be appropriate to have canopy removal levels higher than this level. Regional Water Board staff recommends an exceedance probability of 33% that includes a margin of safety based on the staff's best professional judgment. The Regional Water Board may wish to adjust the margin of safety based on their assessment of risk and the water quality standards.

Table 4. Exceedance probability and canopy removal rates for the 5% allowable increase and a ten year time frame.

Exceedance probability	Freshwater Creek			NF Elk River	
	Corresponding wetness	Acres	Percent of PALCO's ownership	Acres	Percent of PALCO's ownership
5%	28	143	0.92%	101	0.72%
10%	52	173	1.11%	122	0.87%
15%	74	197	1.27%	138	0.98%
20%	95	219	1.41%	152	1.08%
25%	116	239	1.54%	166	1.18%
30%	137	259	1.67%	179	1.27%
33%	150	271	1.75%	187	1.33%
35%	157	278	1.79%	192	1.36%
40%	179	299	1.93%	205	1.45%
45%	200	319	2.06%	218	1.55%
50%	223	342	2.20%	232	1.65%
55%	246	366	2.36%	247	1.75%
60%	271	392	2.53%	264	1.87%

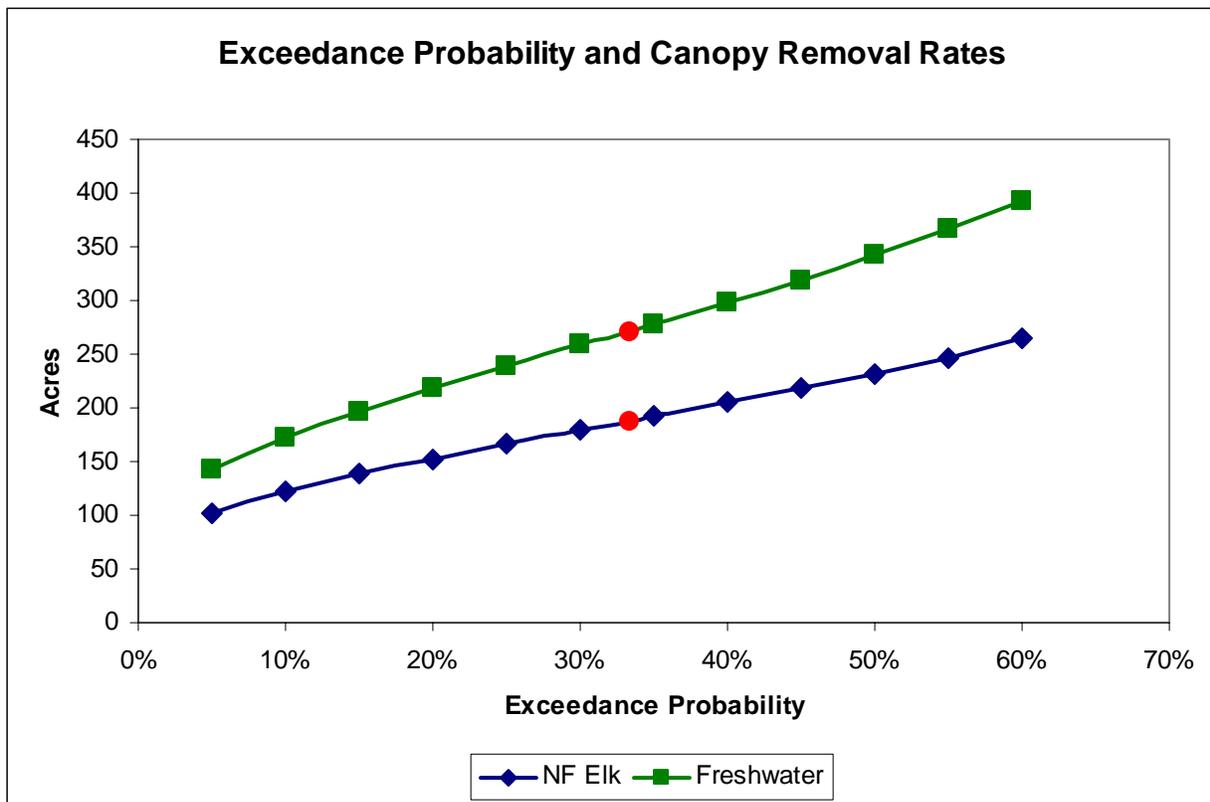


Figure 16. Allowable harvest acres as a function of exceedance probability 5% allowable increase for and a ten year time frame. The red point is the recommended exceedance probability for this permit.

Adaptive Management

As monitoring information shows improvement or degradation in the nuisance flooding conditions, the permit incorporates adaptive management to adjust the allowable harvest rates (Figure 2). If monitoring of the channel cross sections or the stage-discharge relations shows a resulting change in the recurrence interval, this parameter can be adjusted to change the allowable canopy removal rates. The same targets for exceedance probability, allowable increase and timeframe should be used, although these may also be changed. For example, after two years into the permit, there is evidence that the recurrence interval has improved in the North Fork Elk River and nuisance occurs at the 0.4-year recurrence interval. For the remaining eight years, 200 acres of canopy removal per year could be allowed and still reach the 5% target for the 33% exceedance probability. Likewise, if conditions degraded and the recurrence interval lowered to 0.2-year recurrence interval, for the remaining eight year, 178 acres of canopy removal per year could be allowed and still reach the 5% target for the 33% exceedance probability. Furthermore, if channel capacity is actively improved or if infrastructure is improved, adaptive management provisions could remove the canopy removal limitations.

Discussion

The peak flow model is the best available for assessing contribution of canopy removal to increases in peak flows. As with all modeling exercises, there are assumptions, limitations, and uncertainties within the model and its application. These are discussed throughout the report with the key issues highlighted below.

First, two key differences between the Caspar Creek watershed and the target watersheds are their size and road (including skid trails) density and location. Although the size difference between the watersheds will likely lead to an overestimation in peak flows, staff believe this is balanced by the underestimation in peaks flows caused by the differences in road density and location.

Second, the application of the model in this report uses the best available information in determining the input parameters. However, there is some uncertainty associated with the input parameters, particularly with the recurrence interval associated with the current nuisance flooding. As further information on the stage-discharge relationship becomes available, or if there are dramatic changes in the channel capacity, (e.g., channel scour or aggradation, dredging or other reasons) the recurrence interval associated with nuisance flooding will likely change and should be adjusted by the adaptive management provisions within the permit.

The Regional Water Board staff's application of the peak flow model builds upon CDF's application of the peak flow model in Freshwater Creek and Elk River. We determined the frequency of nuisance flood events in these watersheds while CDF defaulted to the 2-year recurrence interval peak flow when no watershed specific information was available. Furthermore, instead of maintaining the current nuisance conditions, we allow for some recovery from the nuisance conditions in these watersheds.

Lisle et al (2000b) employed a 6% exceedance probability (wetness of 50) when they evaluated the increases in peak flow for the Freshwater Creek watershed. CDF (Munn 2001, 2002) employed several values for wetness (50, 304 and 400) to show that their goal of not allowing

further increases is met. Regional Water Board staff recommends the following targets be used in the application of the model: exceedance probability of 33%, 5% allowable increase in peak flow and a ten year time frame to reach the above target.

Modeling Results

Freshwater Creek

Table 5 summarizes the recommended input values for the application of the peak flow model and the resulting clear cut equivalent acres of canopy removal per year for Freshwater Creek.

Table 5. Selected input variable values.

Geographic Extent	Freshwater Creek Planning watersheds: Cloney Gulch, Little Freshwater, Upper Freshwater
Drainage Area	19,688 acres
Harvest History	Based on year harvested <i>Data source: PALCO, CDF</i>
Recurrence Interval	0.4 <i>Based on record of floods at Howard Heights</i>
Exceedance Probability	33% <i>Includes a margin of safety</i>
Recovery Threshold	5%
Recovery time	10 years
Annual Clearcut Equivalent Canopy Removal	271 acres

North Fork Elk River

Table 6 summarizes the recommended input values for the application of the peak flow model and the resulting clear cut equivalent acres of canopy removal per year for North Fork Elk River.

Table 6. Selected input variable values.

Geographic Extent	North Fork Elk River Planning watersheds: Upper North Fork, Lower North Fork
Drainage Area	14,435 acres
Harvest History	Based on year harvested <i>Data source: PALCO, CDF</i>
Recurrence Interval	0.25 <i>Based on record of floods at NFE⁴</i>
Exceedance Probability	33% <i>Includes a margin of safety</i>
Recovery Threshold	5%
Recovery time	10 years
Annual Clearcut Equivalent Canopy Removal	187 acres

⁴ Monitoring Station NFE is located at the intersection of Elk River Road and Wrigley Road on North Fork Elk River, approximately 0.25 stream miles upstream of the confluence with South Fork Elk River.

South Fork Elk River

Regional Water Board staff recommend continued monitoring of the watershed. If monitoring results shows that nuisance flooding does become a problem, adaptive management should be used to incorporate peak flow modeling into the permit.

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Appendix

Information from the following tables was used in the modeling explained in the text of the report. Those data are presented in four tables:

Table 7. Wetness, streamflow and recurrence interval for storms from Caspar Creek.

Table 8. Canopy removal coefficients used to calculate clearcut equivalent acreages from harvest history.

Table 9. Timber harvest history in Freshwater Creek and the North and South forks of Elk River expressed as clearcut equivalent acres.

Table 10. Survey data from Elk River Road.

Table 7. Wetness, streamflow and recurrence interval for storms from Caspar Creek.

storm	startdate	wetness	HI peak (m3/s rank)	RI (years)
	18 881220	59	0.000536	123 0.16
	19 890108	130	0.000603	122 0.16
	42 940122	23	0.000767	121 0.17
	28 910323	117	0.000781	120 0.17
	30 920210	33	0.0007825	119 0.17
	29 910325	138	0.0008085	118 0.17
	33 921208	16	0.000888	117 0.17
	52 951211	13	0.0009275	116 0.17
	27 910319	80	0.000984	115 0.17
	39 930219	331	0.001058	114 0.18
	20 890304	93	0.001198	113 0.18
	36 930106	246	0.0013215	112 0.18
	99 011128	33	0.0013834	111 0.18
	2 860129	128	0.001415	110 0.18
	68 980103	178	0.001426	109 0.18
	64 970120	387	0.0014565	108 0.19
	67 971214	159	0.001459	107 0.19
	103 011216	228	0.0014925	106 0.19
	89 990410	466	0.001497	105 0.19
	114 030412	218	0.001554	104 0.19
	8 860311	444	0.0015675	103 0.19
	25 900521	49	0.001571	102 0.20
	87 990228	482	0.001576	101 0.20
	16 880108	235	0.0016065	100 0.20
	1 860114	60	0.0016415	99 0.20
	40 930222	364	0.0016615	98 0.20
	10 870212	155	0.001672	97 0.21
	102 011213	197	0.0017265	96 0.21
	94 000229	401	0.0017325	95 0.21
	85 990218	403	0.0017375	94 0.21
	112 030215	275	0.0017435	93 0.22
	9 860315	470	0.0017795	92 0.22
	96 010222	141	0.0018115	91 0.22
	12 870311	230	0.001901	90 0.22
	17 881121	18	0.0019165	89 0.22
	60 961204	18	0.001922	88 0.23
	31 920218	124	0.001944	87 0.23
	34 921210	47	0.0019755	86 0.23
	117 031212	35	0.001985	85 0.24
	97 010224	168	0.0020225	84 0.24
	56 960120	224	0.002024	83 0.24
	41 930316	294	0.002037	82 0.24
	51 950321	563	0.002051	81 0.25
	15 880102	182	0.0020545	80 0.25
	118 031213	48	0.002091	79 0.25
	123 040225	356	0.0021035	78 0.26
	86 990224	454	0.002106	77 0.26
	90 000115	81	0.0021135	76 0.26
	113 030314	213	0.002114	75 0.27
	98 010304	191	0.002126	74 0.27
	7 860309	410	0.0021475	73 0.27
	115 030423	254	0.002187	72 0.28
	3 860213	214	0.002199	71 0.28
	58 960218	306	0.002199	70 0.29
	59 960220	337	0.002257	69 0.29
	24 900106	13	0.0023195	68 0.29
	121 040202	234	0.0023275	67 0.30
	54 960115	127	0.002343	66 0.30
	107 021213	10	0.0023445	65 0.31
	23 890323	284	0.0023705	64 0.31
	62 961229	224	0.002378	63 0.32
	76 980216	782	0.0023955	62 0.32
	65 970124	415	0.0024095	61 0.33
	6 860307	379	0.0024155	60 0.33
	81 990122	108	0.0024415	59 0.34
	43 940216	112	0.002523	58 0.34
	11 870304	172	0.0025875	57 0.35

55 960118	175	0.002594	56	0.36
80 981202	53	0.0025955	55	0.36
32 920314	155	0.002602	54	0.37
46 950126	388	0.002616	53	0.38
105 020106	417	0.0026745	52	0.38
21 890308	141	0.002763	51	0.39
74 980202	683	0.0027705	50	0.40
47 950130	436	0.002833	49	0.41
37 930113	300	0.0028565	48	0.42
92 000222	282	0.002865	47	0.43
100 011201	63	0.002913	46	0.43
50 950320	539	0.0029565	45	0.44
5 860218	412	0.003097	44	0.45
95 010219	69	0.003197	43	0.47
22 890317	224	0.0032195	42	0.48
75 980205	728	0.0033475	41	0.49
108 021215	60	0.0033905	40	0.50
73 980128	650	0.003573	39	0.51
13 871204	62	0.003651	38	0.53
110 021230	326	0.0036795	37	0.54
106 020219	232	0.003747	36	0.56
84 990216	334	0.0039735	35	0.57
93 000225	331	0.0039875	34	0.59
116 030428	313	0.004067	33	0.61
122 040216	270	0.004175	32	0.63
101 011205	139	0.004223	31	0.65
71 980116	430	0.0043345	30	0.67
91 000211	201	0.00441	29	0.69
119 031228	134	0.004517	28	0.71
82 990206	156	0.0046315	27	0.74
53 951229	42	0.0047115	26	0.77
77 980219	817	0.0047335	25	0.80
70 980114	347	0.004776	24	0.83
14 871208	144	0.0049305	23	0.87
66 971126	29	0.00501	22	0.91
48 950308	278	0.0051305	21	0.95
78 980221	892	0.0052785	20	1.00
111 030112	336	0.005588	19	1.05
83 990208	242	0.00566	18	1.11
35 921230	116	0.005852	17	1.18
120 031231	205	0.0060875	16	1.25
69 980111	218	0.006727	15	1.33
104 020101	307	0.006887	14	1.43
44 950106	61	0.0071235	13	1.54
26 900526	84	0.007482	12	1.67
57 960124	262	0.007554	11	1.82
45 950111	267	0.007563	10	2.00
109 021227	164	0.007658	9	2.22
72 980125	540	0.008343	8	2.50
4 860215	245	0.008535	7	2.86
79 980321	649	0.0087095	6	3.33
88 990324	426	0.009579	5	4.00
63 961230	242	0.0100045	4	5.00
61 961208	65	0.0100825	3	6.67
49 950313	404	0.0103465	2	10.00
38 930119	374	0.011487	1	20.00

Silvicultural coefficients

Table 8. Canopy removal coefficients used to calculate clearcut equivalent acreages from harvest history.

Silviculture	Coefficient
Clearcut Right-of-way Rehabilitation AP1 ¹	1
Shelterwood Removal Shelterwood Step Seedtree Removal Seedtree Step Salvage AP2 ² AP3 ³ A4 ⁴	0.75
Selection Commercial Thin Thin AP5 ⁵ HCP3 ⁶	0.5

¹ Clearcut

² Seed Tree Seed Step (maintain 15 ft² basal area per acre, maximum 150' spacing between trees)

³ Seed Tree Removal/Shelterwood Removal Step (Remove no more than 50 ft² basal area per acre/Remove no more than 100 ft² basal area per acre)

⁴ Seed Tree Removal/Shelterwood Removal Step (Remove no more than 50 ft² basal area per acre/Remove no more than 100 ft² basal area per acre)

⁵ Shelterwood Step (retain at least 30 ft² basal area per acre)

⁶ Maximum removal of 1/3 conifer basal area per 200 linear feet of Class III watercourse; Thinning will be distributed across all diameter classes; The site will be recaptured within 5 to 10 years; and, All sub and non-merchantable conifers will be left standing onsite if feasible. (Interim HCP measures, 6.3.4.1.4, bullet 16 & 17)

Note: Harvest areas employing the Variable Retention silvicultural prescription were calculated as a combination of clearcut and selection, with the retention areas being calculated as selection.

Harvest History

The harvest history data utilized for Freshwater Creek, North Fork Elk River, and South Fork Elk River are detailed in the following table.

Table 9. Timber harvest history in Freshwater Creek and the North and South forks of Elk River expressed as clearcut equivalent acres.

Year of Harvest	Freshwater Creek Clearcut Equivalent Acres Harvested	North Fork Elk River Clearcut Equivalent Acres Harvested	South Fork Elk River Clearcut Equivalent Acres Harvested
1986	550	155	453
1987	255	129	175
1988	485	1,238	595
1989	224	488	99
1990	486	757	152
1991	439	309	200
1992	327	421	1
1993	318	304	313
1994	492	636	93
1995	75	676	0
1996	917	738	4
1997	1,117	683	483
1998	1,511	711	229
1999	409	82	0
2000	106	0	0
2001	596	7	71
2002	410	364	384
2003	450	639	2
2004	508	395	124

Table 10. Survey data from Elk River Road.

Station (Feet)	BS	FS	HI	Elevation	Left EOP	Centerline	Right EOP	Edge of Berm	Description	Elevation Left EOP	Elevation Centerline	Elevation Right EOP	Elevation Edge of Berm
BM1	5.15		61.75	56.6					Shiner on left edge of pavement adjacent to "Headwaters Forest Reserve" sign				
BM2	0.97		61.75	60.78					Right (US, NE) corner bridge rail				
BM3	1.2		61.75	60.55					NW corner bridge rail				
Bm4	1.7		61.75	60.05					Top of 19.99' staff				
BM5	5.06		61.75	56.69					Top of 16.66' staff				
BM6	8.41		61.75	53.34					Top of 13.33' staff				
0			61.75		5.81	6	6.6		Start at orange spray paint on left edge pavement south of concrete bridge on Elk River Rd	55.94	55.75	55.15	
24			61.75		5.52	5.85	6.58			56.23	55.9	55.17	
48			61.75		6.74	5.94	6.32		3' south bridge abutment	55.01	55.81	55.43	
72			61.75		5.3	5.35	5.71			56.45	56.4	56.04	
96			61.75		4.31	4.28	4.49			57.44	57.47	57.26	
120			61.75		4.12	3.98	4.1			57.63	57.77	57.65	
144			61.75		4.13	3.94	4.12			57.62	57.81	57.63	
168			61.75		4.35	4.08	4.28			57.4	57.67	57.47	
192			61.75		4.81	4.54	4.62		2' north of abutment	56.94	57.21	57.13	
216			61.75		5.3	4.95	4.81		2' north of BM1	56.45	56.8	56.94	
240			61.75		5.73	5.54	5.57		5' south of large tree	56.02	56.21	56.18	
264			61.75		6.04	6	6.79		1.5' south of "one lane bridge" sign, 5' north of large diam redwood	55.71	55.75	54.96	
288			61.75		6.6	-	6.82			55.15		54.93	
312			61.75		7.15	7.83	7.87			54.6	53.92	53.88	
336			61.75		7.44	7.07	7.34			54.31	54.68	54.41	
360			61.75		7.46	7.06	7.25		south end of elbow stripe adjacent to "35MPH" sign	54.29	54.69	54.5	
384			61.75		7.32	7.08	7.16			54.43	54.67	54.59	
408			61.75		7.44	7.03	7.28			54.31	54.72	54.47	
432			61.75		7.6	7.08	7.27			54.15	54.67	54.48	
BM7		5.95	61.75	55.8					Nail in pole by bigfruit tree, town side of Kallo Yard				
BM7	5.2		61										
456			61		6.58	6.36	6.82			54.42	54.64	54.18	
480			61		6.53	6.41	6.87		North side of yellow stripe @ pole with BM7	54.47	54.59	54.13	
504			61		6.22	6.66	7.41			54.78	54.34	53.59	
528			61		6.58	6.36	6.82		Middle yellow stripe south of culvert @ REOP	54.42	54.64	54.18	
541.2			61			6.9	7.69	8.41	Culvert		54.1	53.31	52.59
			61		6.2	6.99	8		Just above LEOP is break in slope at 7.68	54.8	54.01	53	
552			61		6.32	6.92	8.01		Section of road with broken pavement	54.68	54.08	52.99	
576			61		5.99	6.79	7.64			55.01	54.21	53.36	
576.2	33.5		61			6.94	7.87	8.17	Break in Berm		54.06	53.13	52.83
600			61		5.78	6.47	7.55			55.22	54.53	53.45	
624			61		5.65	6.36	7.46			55.35	54.64	53.54	
648			61		5.15	5.97	7.14		Base of big stump	55.85	55.03	53.86	
672			61		4.66	5.6	6.44		Paved	56.34	55.4	54.56	
696			61		4.2	5.3	6.44			56.8	55.7	54.56	
720			61		3.8	4.59	6		-Crit dip of watercourse	57.2	56.41	55	
744			61		2.72	3.44	4.97		-3' South of Pole	58.28	57.56	56.03	
768			61		1.79	2.26	2.28		North End of Survey	59.21	58.74	58.72	

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