ANALYSIS OF THE EFFECT OF PROPOSED SITE RECLAMATION ON THE WATER REGIME OF *SEQUOIADENDRON GIGANTEUM*, MERCED AND TUOLUMNE GROVES, YOSEMITE NATIONAL PARK, CALIFORNIA

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PURPOSE

The purpose of this analysis is to provide a qualitative assessment of the effects of site reclamation on the water regime of Sequoiadendron Giganteum as it pertains to the implementation of Development Concept Plans for the Tuolumne and Merced Groves, Yosemite National Park, California. In addition, alternatives for quantifying the effects of site reclamation on water regimes are developed.

In general, it is deduced that the overall effect of site reclamation will be to reduce surface runoff, increase soil infiltration capacities and increase the total delivery of water to the root zones of the subject trees. However, water supply increases will be achieved gradually and will not be large in comparison to overall water delivery to the trees. Furthermore, soil water conditions known to be deleterious to tree vigor (i.e. saturation) will not be caused by the proposed reclamation alternatives. All reclamation activities will have to be conducted so as not to sever or physically damage sequoia roots.

ISSUE STATEMENT

Plans are being developed to change the way visitors are accommodated at both the Mariposa and Tuolumne Sequoia Groves. Planning alternatives involve relocating roads, parking facilities, and some trails away from the sequoia groves, and restoring more natural understory vegetation and soil conditions. In the case of the Mariposa Grove, parking would be provided downgradient from the grove, and the present paved parking lot would be removed, and compacted soils scarified and revegetated. At the Tuolumni Grove, it is proposed that the present small dirt parking lot, as well as several of the informal trails resulting from unmanaged visitor use, be scarified, water-barred as necessary, mulched, and revegetated.

At both groves there is concern that restoration activities, especially asphalt removal and soil scarification, will cause sudden changes in water availability in the root zone, and that these changes will shock or stress the trees. While it is generally understood that reclamation will result in more "natural" soil and hydrologic conditions, there exists the possibility that the trees have adjusted to the present, unimpaired state which has existed for over 100 years in both groves.

LITERATURE REVIEW

Sequoias are very locally distributed along the western slope of the Sierra Nevada mountains in California. They generally occur between 1,700- and 2,100-m elevation in Yosemite where annual precipitation is approximately 1,140-1,520 mm and occurs predominately in the form of snowfall during the winter season (Harvey, et al., 1981). Sequoias occupy sites where soils typically are shallow, coarse grained, poorly developed, and of granitic (although non-glacial) origin (Muir, 1877). Sequoias also occupy alluvial bottoms where soils are finer grained, better developed, and well-drained (Schubert, 1957). A forest duff layer contributes to soil character in less disturbed sites.

Soil infiltration capacities and saturated conductivities are high. In the Mariposa Grove, final infiltration capacities ranged from roughly 250 to 6400 mm/hr for undisturbed sites and from 130 to 600 mm/hr for severely compacted sites (Hartesveldt, 1962). These high measured infiltration rates are attributed to the large amount of macro-porosity usually associated with sandy or well-developed loam soils. Soil silt contents (at the Mariposa Grove) varied from 9-20 percent for sandy soils, and clay contents were typically very low, ranging from 0.2-10 percent. Clay contents for alluvial soils were higher, ranging from 15 percent in the upper 0.3 m to as high as 50 percent in the "B" soil horizon (Hartesveldt, 1962).

Sequoia root systems are shallow and radiate laterally up to 66 m from the main tree trunk (Hartesveldt, 1962). Sequoias have an enormous capacity to transpire water, which greatly exceeds the amount of water delivered by direct infiltration to the root zone (Rundel, 1972). Sequoias require well drained soils which remain moist over much of the growing season (Harvey, et al., 1981). To achieve this apparent anomalous condition, it is believed that most sequoias require sites near valley bottom drainages, or on hillslopes where on-site soil water contributions are augmented by shallow ground water or interflow from upslope (Hartesveldt, 1962; Harvey, et al., 1981, Rundel, 1972). Thus, it is strongly suggested in the literature that water demands are met both by water which infiltrates directly into the sequoia root zone from snowmelt, and water which is delivered to the root zone from upgradient, either by surface or subsurface processes.

Also, it might be deduced that sequoias are able to tolerate drought conditions. Both seasonal dry periods caused by prolonged periods of little or no precipitation (summer), and longer-term drought cycles, which undoubtedly have occurred over the life history (2,000 yrs. or more) of the larger trees, suggest that the trees survive periods of low water availability. In fact, Muir (1877) suggests that they may be better adapted than associated tree species to tolerating temporary drought periods. Although sequoia trees seem to tolerate drought, their growth vigor as measured by tree-ring widths is likely affected. Evidence supporting the notion that reduced water availability restricts growth, is provided by Hartesveldt (1962) where trees impacted by severed roots (up to 30 percent root capacity loss) were found to exhibit reduced growth rates compared to trees with unsevered root systems.

Whereas sequoia trees seem to tolerate periods of drought, there is evidence that they experience enhanced vigor when water is plentiful, provided that soils remain well drained and unsaturated. Hartesveldt (1962) examined tree vigor based upon growth rates for trees subjected to increased soil water availability resulting from creation of an artificial wet meadow. He found significant increases in growth rates in all trees except those subject to prolonged periods of soil saturation. Where soils were saturated, trees experienced growth stress and even mortality.

While water quantities supplied to root zones from upslope (surface water and ground water/interflow) are difficult to quantify, the amount and rate of water supplied by snowmelt and direct infiltration can be approximated. Assuming saturated springtime snowpack conditions, and applying the generalized snowmelt formula (U.S. Army Corps of Engineers, 1956)

$$M = (0.19\,T2 + 0.17\,Td) \qquad (1)$$

where

M = melt rate in cm/day
T2 = mean air temperature (centigrade) 2 m above the snowpack
Td = dew point temperature (centigrade)

it is likely that melt rates as great as 20-30 mm/day; can be achieved (this works out to be approximately 2.5-3.7 mm/hr assuming an 8-hour daily melt period). This estimate assumes that the value of T2 is 10 deg. C and Td is 2 deg. C. We cannot surmise the effects of frozen soils on infiltration capacities, but the maximum melt rates calculated above are substantially less than infiltration capacities reported above by Hartesveldt (1962). And, while frozen soils likely reduce infiltration capacities, they would only affect infiltration volumes under conditions where infiltration capacities were reduced below snowmelt rates.

Summer thunderstorms also occur at sequoia sites. However, these storms are not common, generally are of short duration and high intensity, and likely do not provide substantial soil moisture recharge at sequoia root zone depths. Thunderstorms likely are responsible for occurrences of direct surface runoff and episodes of on-site rill and interrill erosion.

In summary, a cursory review of the literature suggests that sequoias occupy moist, well-drained sites where water is supplied both by direct infiltration of snowmelt, and delivery of upslope water to the root zone by both surface and subsurface processes. Sequoias seem to tolerate periods of drought, but growth rates may be reduced. Sequoias seem to respond to increased water supplies, provided that root zones remain unsaturated and well-drained.

ANALYSIS

Based upon cursory review of the literature and reconnaissance-level site assessments conducted November 16-17, 1989, I believe that the proposed reclamation alternatives will increase the delivery of water to the subject sequoia trees by direct infiltration processes. Based upon a comparison of measured infiltration rates to soil infiltration capacities, I believed that all but the most severely compacted sites (e.g., the Tuolumni Grove parking area, visitor trails), and paved sites (e.g., roads, Merced Grove parking lot), infiltrate most available snowmelt water. Severely compacted sites probably generate surface runoff during snowmelt, some of which likely is not completely reinfiltrated within the root zones of subject trees. Also, moderately and severely compacted sites likely generate surface runoff during periods of short-duration high-intensity summer thunderstorms. Again, the generated surface runoff likely is not reinfiltrated within the root zones of subject trees.

While direct measurements were not made, and assuming that the average root zone covered an area of 8,000 m^2, it was our observation that severely compacted sites did not comprise more than roughly 10-30 percent of the root zone areas of the subject trees (an exception being trees in the Merced Grove, surrounded by a parking lot, where up to 50-70 percent of the root zone area may be severely compacted). As discussed above, it is generally agreed that sequoias obtain a substantial portion of their water supply by upslope delivery of surface water and ground water. Therefore, the reduction in water delivery caused by severe compaction or paving does not equate to the proportion of root zone area affected, but is, in fact, considerably less (and also is in proportion to the ratio of infiltrated to upslope-delivered water). We have no way of estimating the contribution to total water use by upslope water deliveries, but based upon the high evapotranspiration capacities of sequoias compared to the total potential infiltrated water (1270 mm times the root zone area = 10,000 m^3), it is possible that a majority of the water used by sequoias is generated offsite (upslope). Therefore, increases in water delivery resulting from restoring more natural infiltration capacities of severely impacted sites will have, proportionally, only a small affect on the total delivery of water to the subject sequoias.

Furthermore, while we don't care to speculate on the probable physiologic response of the subject trees to increased water supplies, we did find evidence in the literature to suggest that sequoias exhibit increased growth vigor in response to increased water supplies, provided that soils remain unsaturated and well-drained.

CONCLUSIONS

The information gleaned from a cursory literature review and reconnaissance level site visits suggests that the effects of proposed site reclamation plans on water regimes of sequoias will be to reduce surface runoff, increase soil infiltration capacities, and increase the total delivery of water to the root zones of the subject trees. However, water supply increases are not likely to be large in comparison to overall water delivery to the trees. The water regime may be beneficial to tree vigor, provided that saturated soil conditions are not generated and tree roots are not physically impacted. It is our opinion that saturated soil conditions will not result from the proposed reclamation activities. Reclamation will have to be conducted so as not to sever or physically damage sequoia tree roots. Our conclusions are based upon a qualitative assessment of site conditions. Given the priceless value of the subject trees, additional quantification and analysis is warranted (see Recommendations).

RECOMMENDATIONS

While I believe that the effects of alternative reclamation plans on the water regimes of sequoia trees generally will be small, and likely beneficial to the trees, additional hydrologic quantification may be warranted. In addition, interpretation of the effects of altered hydrologic regime on the subject sequoia trees by professional plant physiologists is recommended. Alternatives for additional hydrologic quantification include:

1. Field experimentation (infiltration rates, melt rates), and

2. Modeling (combined with a minimum level of field measurement and validation.

Modeling would require carefully surveying topography and delineating root zone areas, contributing subbasins, and soil conditions (compacted, less disturbed). Based upon soil physical properties and snowmelt and infiltration modeling, a water budget could be developed for both the existing condition and one or more alternative rehabilitated conditions. A number of generally accepted models exist for this type of analysis. We would recommend snowmelt modelling based upon energy balance methods, and infiltration modeling based upon the Green and Ampt infiltration equation. Some field validation of assumed infiltration capacities for both the existing and reclaimed conditions would add confidence to the modeling estimates. A modeling analysis of this type might be expected to cost between $5,000 to $8,000, if contracted. An analysis of this type also could be conducted by the NPS Water Resources Division as programmed technical assistance or by other NPS entities.

Field experimentation would best be based on **a)** a field infiltration study (frozen and unfrozen soils), **b)** measured snowmelt rates, **c)** soil moisture monitoring, **d)** soil physical analyses, and **e)** quantification of upslope water deliveries. Soil and infiltration analyses would have to be conducted on both impacted and simulated rehabilitated conditions. A field experiment could be based upon published, well-accepted methods and would require approximately one year to conduct. A field study of this type might be expected to cost between $25,000 to $40,000.

While I believe that the qualitative analysis of the effects of site reclamation on the water regimes of sequoias presented here is sound, we suggest that it would be appropriate to conduct a modeling-based quantification as recommended above as part of the Environmental Assessment for the preferred rehabilitation alternative. A more quantified analysis of this type would provide a sound basis for the interpretation of the effects of changed water regimes on sequoias by qualified physiologists. Because methods are well developed for the sort of modeling analysis recommended above, we believe that a detailed field study is unwarranted given its likely cost. Also, we believe that the critical link in the overall analysis will not be in quantifying the hydrologic effects of reclamation, but rather interpreting those effects in terms of the well-being of the subject trees.

LITERATURE CITED

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