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STAFF REPORT

Date: February 16, 2022

To: TRPA Governing Board

From: TRPA Staff

Subject: Discussion and possible action/recommendation of Forest Health Code Language Regarding Mechanical Ground-based Equipment on 30-50% Slopes, Chapter 61 Vegetation and Forest Health- Sections 61.1.6.B. through 6.1.1.6.D

<u>Summary and Staff Recommendation:</u>
Chapter 61 of the TRPA Code of Ordinances addresses vegetation management and forest health. Staff will present an overview of and potential amendments to Section 61.1.6.B. through 61.1.6.D. regarding Minimum Standards for Tree Removal including the use of ground-based mechanical equipment on 30% to 50% slopes. Staff seeks Governing Board discussion and recommendation to TRPA Governing Board for adoption of the proposed Chapter 61.1.6 Code amendments.

<u>Motion:</u>
To recommend adoption of the ordinance amendments, Governing Board must make the following motion(s), based on the staff summary:

1) A motion to recommend approval of the Required Findings, as described in Attachment B, including a Finding of No Significant Effect, for adoption of the Code of Ordinance amendments as described in the staff summary; and,
2) A motion to recommend adoption of the Ordinance 2022 -___, amending Ordinance 87-9, to amend the Code of Ordinances as shown in Attachment A.

For the motions to pass, an affirmative vote of four members from each state is required.

These proposed amendments were approved and recommended for consideration by the Forest Health and Wildfire Committee in November 2021 and by the Regional Plan Implementation Committee in January 2022. In February 2022, the Advisory Planning Commission (APC) recommended these amendments for Governing Board review and approval with changes to Table 61.1.6.-4 to reference the correct code sections. Additionally, in response to comments from the APC, TRPA Staff adjusted the analysis in the IEC on Scenic Resources/Community Design (Sections 18a and 18b) to reflect that there may be visible impacts during and after treatment; however, scenic impacts from the projects will be positive and representative of reduced stand densities indicative of healthy, resilient forests.

Proposed Revisions to Section 61.1.6.B. Logging Roads, Skid Trails, and Landings through 61.1.6.D. Skidding and Ground-Based Vehicle Systems:

Active forest management and treatments are critical to increase forest and ecosystem resilience to disturbance such as fire, insects and disease, and climate change. There are a variety of ways to accomplish forest treatments including mechanical ground-based equipment and thinning, broadcast burning, and hand thinning and subsequent pile burning. Currently, under the TRPA Code of Ordinances implementors use ground-based mechanical equipment for thinning treatments on slopes up to 30%. For slopes above 30%, implementors must hand treat acres, usually leaving hand piles for burning in later years. Hand treatment and pile burning are often more costly, labor intensive, and less ecologically beneficial than mechanical thinning and subsequent broadcast prescribed burning. Additionally, limiting ground-based mechanical equipment to only slopes 30% or less limits the pace and scale of treatment, which is counterproductive to increased forest resilience and decreased risk of catastrophic wildfire.

In July 2021, Staff and partner scientists presented to the Forest Health and Wildfire Committee findings from the Water Erosion Prediction Project (WEPP) analysis regarding the erosion risk and water quality impacts from ground-based mechanical equipment and treatment on slopes 30% to 50% within the basin. This research and report found that potential erosion and sedimentation risk could be mitigated through environmental protection measures including remaining ground cover post-treatment, buffers, use low impact equipment and technology, and varying slope length for treatment. Additionally, the erosion risk associated with a high-severity wildfire on slopes 30% to 50% in many areas of the basin substantially higher than erosion risk associated with the use of ground-based mechanical equipment.

Ultimately, analyzing the soil erosion as an average for all the hillslopes and modeled conditions in the basin, the researchers found, overall, all thinning scenarios narrowly increased sediment and phosphorus yields but not as much as a moderate or high severity fire. Results show that managers would need to apply thinning treatments more than 50 times within 60 years to generate erosion that would eliminate the benefits of reducing wildfire severity from moderate to low. Additionally, the researchers found most sediment yield on slopes between 30% and 50% comes from areas covered by shrubs and grasses and not from forested areas. The report demonstrated that on hillslopes between 30% and 50% thinning will increase the risk of erosion, but when thinned hillslopes erode, the sediment yield is no different when compared to an untreated hillslope.

Based on this research, staff proposes amendments to 61.1.6.B. Logging Roads, Skids Trails, and Landings through 61.1.6.D. Skidding and Ground-Based Vehicle Systems to allow mechanical ground-based equipment and treatments on slopes 30% to 50%. The proposed amendments have been collaboratively discussed and designed with the Tahoe Fire and Fuels Team’s Regulations Working Group and include modifying code language and adding clarification where necessary.

Proposed Amendments for clarification and standardization with current code:

1. Inclusion of “over frozen ground” tree removal.
2. Refinement of equipment definitions to reflect current technology and practices.

Proposed Amendments to expand treatments:

1. Refinement of Table 61.1.6-3 to reflect California Practice Act water break spacing on slopes up to 50%.
2. Refinement of Table 61.1.6-4 to reflect expanded treatment practices (use of ground-based mechanical equipment) on Land Capability Districts 1a, 1c, 2 (areas over 30% slopes).

3. Inclusion of language that allows for skidding and the use of ground-based mechanical equipment on 30% to 50% slopes with TRPA approval when slope erosion is minimized.

Environmental Review:
The Code amendments have been reviewed in an Initial Environmental Checklist (IEC) pursuant to Chapter 3: Environmental Documentation of the TRPA Code of Ordinances and Article VI of the Rules of Procedure. The IEC finds that the proposed amendments would not result in significant effects on the environment (see Attachment C).

Regional Plan Compliance:
The proposed amendments to the Code of Ordinances are consistent with the Vegetation Sub-element, a component of the Regional Plan's Conservation Element.

Contact Information:
For questions regarding this agenda item, please contact Kathleen McIntyre, at (775) 589-5268 or kmcintyre@trpa.org.

Attachments:

A. Adopting Ordinance
    Exhibit 1: Tracked Code Amendments
B. Required Findings/Rationale
C. Initial Environmental Checklist (IEC)
D. Dobre et al. 2021. *"Assessing the Effects of Forest Treatments and Wildfires on Sediment Yield in the Lake Tahoe Basin."* Draft WEPP Analysis Report.

Attachment A

Adopting Ordinance

Attachment A

TAHOE REGIONAL PLANNING AGENCY
ORDINANCE 2022-

AN AMENDMENT TO ORDINANCE NO. 87-9, AS AMENDED, TO AMEND THE TRPA CODE OF ORDINANCES, CHAPTER 61 REGARDING VEGETATION PROTECTION AND MANAGEMENT.

The Governing Board of the Tahoe Regional Planning Agency does ordain as follows:

Section 1.00 Findings

1.10 It is desirable to amend TRPA Ordinance 87-9, as previously amended, by amending the TRPA Code of Ordinances to further implement the Regional Plan pursuant to Article VI (a) and other applicable provisions of the Tahoe Regional Planning Compact.

1.20 The TRPA Code of Ordinances Chapter 61.1 amendments were the subject of an Initial Environmental Checklist (IEC), which was processed in accordance with Chapter 3: *Environmental Documentation* of the TRPA Code of Ordinances and Article VI of the Rules of Procedure. The TRPA Code of Ordinances amendments have been determined not to have a significant effect on the environment, and are therefore exempt from the requirement of an Environmental Impact Statement (EIS) pursuant to Article VII of the Compact.

1.30 The Advisory Planning Commission (APC) and the Governing Board have each conducted a noticed public hearing on the proposed TRPA Code of Ordinances Chapter 61.1 amendments. The APC has recommended Governing Board adoption of the necessary findings and adopting ordinance. At these hearings, oral testimony and documentary evidence were received and considered.

1.40 The Governing Board finds that the TRPA Code of Ordinances amendments adopted hereby will continue to implement the Regional Plan, as amended, in a manner that achieves and maintains the adopted environmental threshold carrying capacities as required by Article V(c) of the Compact.

1.50 Prior to the adoption of this ordinance, the Governing Board made the findings required by Section 4.5 of the TRPA Code of Ordinances, and Article V(g) of the Compact.

1.60 Each of the foregoing findings is supported by substantial evidence in the record.

Section 2.00 TRPA Code of Ordinances Amendments

Ordinance 87-9, as previously amended, is hereby amended by amending Chapter 61.1 of the TRPA Code of Ordinances, as set forth in Exhibit 1.

Section 3.00 Interpretation and Severability

The provisions of this ordinance amending the TRPA Code of Ordinances adopted hereby shall be liberally construed to affect their purposes. If any section, clause, provision or portion thereof is declared unconstitutional or invalid by a court of competent jurisdiction, the remainder of this ordinance and the amendments to the Regional Plan Package shall not be affected thereby. For this purpose, the provisions of this ordinance and the amendments to the Regional Plan Package are hereby declared respectively severable.

Section 4.00 Effective Date

The provisions of this ordinance amending the TRPA Code of Ordinances shall become effective on (Insert Month) XX, 2022.

PASSED AND ADOPTED by the Governing Board of the Tahoe Regional Planning Agency at a regular meeting held on (Insert Month) XX, 2022, by the following vote:

Ayes:

Nays:

Abstentions:

Absent:

____
Mark Bruce, Chair
Tahoe Regional Planning Agency,
Governing Board

Attachment A: Exhibit 1

Tracked Code Amendments

AGENDA ITEM NO. VI.A.

CHAPTER 61: VEGETATION AND FOREST HEALTH

61.1. TREE REMOVAL

61.1.1. Purpose

The purpose of this section is to regulate the management of forest resources to achieve and maintain the environmental threshold standards for species and structural diversity, to promote the long-term health of natural resources, to restore and maintain suitable habitats for native wildlife species, and to reduce accumulations of hazardous fuels in order to decrease the likelihood of catastrophic wildfire events.

61.1.2. Applicability

TRPA requires the protection and maintenance of all native vegetation types. TRPA may require the preparation and implementation of a remedial vegetation management plan for any parcel where the need for remedial vegetation management has been identified for purposes of environmental threshold maintenance or attainment. The use, protection, and maintenance of vegetation are also addressed in the following chapters of the Code of Ordinances:

A. 2: *Applicability of the Code of Ordinances*;

B. 30: *Land Coverage*;

C. 33: *Grading and Construction*;

D. 36: *Design Standards*;

E. 53: *Individual Parcel Evaluation System*;

F. 60: *Water Quality*;

G. 61: *Vegetation and Forest Health*;

H. 62: *Wildlife Resources*;

I. 63: *Fish Resources*;

J. 64: *Livestock Grazing*;

K. 80: *Review of Projects in the Shorezone and Lakezone*;

L. 84: *Development Standards Lakeward of High Water*; and

M. 90: *Definitions*.

61.1.3. Delegation of Project Review and Permit Determination

Qualified agencies, or third party designees, may be delegated authority for permit determinations set forth in this chapter. Stream environment zone areas (SEZ's) may be excluded from the delegation. TRPA may, on a case-by-case basis, designate the review of SEZ's if the agency or third party has demonstrated expertise in hydrology, ecology, botany, restoration, soil science, or similar scientific disciples and are qualified to evaluate and prevent negative impacts to SEZ's and water quality. If TRPA delegates these review and permitting functions, these agencies will also be responsible for ensuring compliance with all other provisions of the Compact, Regional Plan, and Code of Ordinances.

61.1.4. Reasons for Tree Removal

Except for trees identified for retention under subsection 61.3.7, tree removal shall incorporate measures and prescriptions that promote a range of threshold standards and SEZs pursuant to subsection 61.3.3.C. Trees may be removed for the reasons provided below.

A. Hazardous Tree Removal

To protect lives and property, trees reported by a qualified forester to be hazardous to property or lives may be removed upon approval by TRPA unless otherwise exempt through a Memorandum of Understanding. Other vegetation shall be protected during removal operations to prevent their damage.

1. Fire Hazard Tree Removal

Trees identified and marked by a qualified forester as a fire hazard may be removed upon approval by TRPA or pursuant to a TRPA MOU Authorization. Trees identified and marked by a defensible space assessor for defensible space purposes associated with a building or structure may be removed upon approval by TRPA or pursuant to a TRPA MOU Authorization. Fuel reduction projects shall consider multiple threshold objectives. As an alternative to tree removal, the defensible space assessor may approve the limbing of trees that are determined to be a fire hazard, consistent with defensible space requirement of the applicable fire agency. (See Chapter 90 for definition of "fuels management.")

2. Emergency Tree Removal

When a tree constitutes a physical emergency (e.g., imminent threat of falling on occupied or substantial structures or people), the tree may be removed, but the land owner or manager shall provide photographic documentation and all applicable paperwork and fees to TRPA within ten working days of removal of the hazardous tree.

3. Tree Removal During Emergency Fire Suppression Activities

Trees may be removed when an emergency fire suppression need exists as determined by the local, state, or federal fire suppression agency involved in a fire suppression activity.

B. Ecosystem Management Goals and EIP Projects

1. Management Objectives

Trees may be removed to meet ecosystem management goals:

a. Restoration and expansion of stream environment zones and riparian vegetation;

b. Improvement of the structural diversity of all forests based on judgement of a qualified forester;

c. Enhancement of native wildlife species and/or native wildlife habitat diversity;

d. Enhancement and protection of tree species of limited occurrence, such as aspen, black cottonwood, ponderosa pine, Douglas-fir, incense-cedar, sugar pine, western white pine, mountain hemlock, whitebark pine, and western juniper;

e. Protection of sensitive lands;

f. Minimization of construction of new roads;

g. Revegetation of existing temporary roads;

h. Avoidance of disturbance of stream environment zones, unless such project is to enhance the health of stream environment zones through projects intended to thin trees or prescribe burn within SEZ in accordance with subparagraph 61.3.3.C;

i. Utilization of existing openings or disturbed areas as landings where appropriate;

j. The promotion of a diversity of seral stages, species diversity, and age class;

k. Fuels management for fire hazard reduction; and

l. Forest health and resilience to drought, insects, disease, and climate change.

2. Dead, Dying, or Diseased Tree Removal

To enhance forest health, dying, or diseased trees may be removed upon approval by TRPA Dead trees less than or equal to 30 inches in westside forest types and less than or equal to 24 inches in eastside forest types may be removed without TRPA approval pursuant to subsection 2.3.2.E.

3. Tree Removal for Early Successional Stage Vegetation Management

Tree removal may be permitted when it has been determined by TRPA that it is appropriate to convert an area to, and/or maintain an area in, an early successional stage vegetation type. (See Chapter 90 for definition of "early successional stage vegetation management.") Where soil stabilization is required and/or the replacement of removed vegetation, the applicant shall provide a revegetation or soil stabilization plan in accordance with subsection 61.4.5.

4. Tree Removal for Enhancement of Forest Health and Diversity

Tree removal may be permitted where the species or structural diversity of an area is not in accordance with management objectives. TRPA shall apply the criteria below in reviewing tree removal to enhance forest health and diversity.

a. A management plan that demonstrates the need for the project and the means of accomplishing the objectives listed below shall be prepared by a qualified forester.

(i) Removal of trees shall not result in less than minimum stocking levels required by the applicable state or federal forestry agency.

(ii) If improved structural diversity is the objective, removal of trees shall be linked to a reforestation program that provides for the establishment of younger-aged trees, or be accompanied by a report from a qualified forester that states the reasons why a reforestation plan is not necessary to achieve structural diversity objectives.

(iii) If improved species diversity is the objective, removal of trees shall be linked to a reforestation program that provides for the establishment of native species other than the local dominant, or be accompanied by a report from a qualified forester that states the reasons why a reforestation plan is not necessary to achieve species diversity objectives.

(iv) On parcels of three acres or less, the tree removal permit may serve as the management plan.

b. The site proposed for tree removal for forest diversity shall be within a contiguous area of at least three acres in which a single tree species of similar age class dominates. There is no minimum acreage when removing trees for forest health or for successional management of stream environment zones.

C. Tree Removal for Solar Access

Removal of healthy trees to maximize efficiency of solar energy systems may be permitted according to the standards below.

1. TRPA may approve the removal of healthy trees provided TRPA finds that the trees unreasonably impede the operation of a solar energy system and that the solar energy system is properly located so as to minimize the need for tree removal.

2. The number of healthy trees that may be removed for the system's operation shall be the minimum necessary.

3. The only trees that shall be considered for removal for an active or passive solar energy system are those that lie generally south of the proposed solar collector and are in the sun's path between an 18∞ vertical angle measured from the base of the solar collector and a 70∞ vertical angle from the same base measurement. Trees on adjacent properties may be removed provided a contractual agreement to allow for such removal is signed by the affected parties. Tree removal may be conditioned upon replacement elsewhere on the property.

D. Public Utility Rights-of-Way

The removal of trees within utility and public rights-of-way may be allowed if TRPA finds that the removal is for public health and safety. When a tree-related emergency exists, the utility or public agency may remove the trees and advise TRPA of the action on the next business day. At that time TRPA may issue an emergency permit in accordance with its Rules of Procedure.

E. Tree Removal for Ski Areas

For expansion of ski areas, including but not limited to, the widening of runs and the addition or replacement of lifts, only the minimum number of trees necessary for the operation of the ski area shall be removed.

F. Tree Removal for Development

Tree removal for development in conjunction with a TRPA permit shall be in accordance with the provisions of this chapter and Section 33.6.

G. Tree Removal to Enhance Scenic View Points from Public Roadways

Select trees may be removed to enhance scenic viewpoints from scenic turnouts located on highways, public right-of-ways and other public lands immediately adjacent to highway corridors.

61.1.5. General Tree Removal Standards

The cutting, moving, removing, killing, or materially damaging of live trees, and the attachment of appurtenances to trees, shall comply with this subsection. The removal of trees 14 inches dbh or less shall be exempt from TRPA approval under subparagraph 2.3.2.M and requirements of this chapter, except as provided herein. Removal of trees greater than 14 inches dbh shall require approval by TRPA except as provided in subparagraphs 61.1.4.A.2 and 61.1.4.A.3. Removal of trees greater than six inches dbh on lakefront properties where the trees to be removed provide vegetative screening of existing structures as viewed from Lake Tahoe requires TRPA approval, except as provided in subsections 61.1.4.A.2 and 61.1.4.A.3. Permits shall be granted or denied in conformity with the provisions of this chapter.

A. Additional Code Standards

Such tree-related projects and activities also shall conform to the provisions of the Code as provided below.

1. If vegetative screening is required by an existing permit for any property, the vegetative screening shall not be removed without prior approval from TRPA except for defensible space purposes pursuant to subparagraph 61.3.6.D.

2. If tree and/or vegetation removal to occur on any property where existing permit conditions require retention of vegetation, including tree and/or vegetation removal for defensible space purposes pursuant to subparagraph 61.3.6.D, alternative scenic mitigation shall be proposed to TRPA within 30 days of vegetation removal and shall be subject to review and approval by TRPA notwithstanding the permit exemption in subparagraph 2.3.2.M.

B. Findings

Before tree-related projects and activities are approved by TRPA, TRPA shall find, based on a report from a qualified forester, that the project or activity is consistent with this chapter and the Code. TRPA may delegate permit issuance to a federal, state, or other qualified agency through a memorandum of understanding.

C. Harvest or Tree Removal Plan

In cases of substantial tree removal, as set forth in subparagraph 61.1.8, the applicant shall submit a harvest plan or tree removal plan prepared by a qualified forester. The plan shall set forth prescriptions for tree removal, water quality protection, vegetation protection, residual stocking levels, reforestation, slash disposal, fire protection, and other appropriate considerations. The plan, as approved by TRPA, shall become a part of the project and prescriptions contained in the plan shall be conditions of approval. TRPA may consider plans developed pursuant to the California Forest Practice Rules or other CEQA documents completed by a qualified forester to meet the intention of this section provided all the required elements are addressed.

61.1.6. Minimum Standards for Tree Removal

The minimum standards for tree removal shall be as provided below.

A. Cutting Practices

The following cutting practice standards apply:

1. Sufficient trees shall be reserved and left uncut and undamaged to meet the minimum acceptable stocking standards of the appropriate state or federal forestry agency, except in cases of early successional stage management;

2. Group selections shall be limited to use for achieving management objectives based on the judgement of a qualified forester. Group selections shall be limited in size to less than five acres (See subparagraph 61.1.6);

3. All live trees to be cut shall be marked on bole and stump with paint by, or under the supervision of, a qualified forester prior to TRPA approval.

Trees to be removed or protected may be designated by other means in situations involving clear cuts or thinning of exceptionally dense thickets, or other situations that warrant an alternate method of designation. The alternate method shall be stated in the plans and must be approved by TRPA;

4. Damage to unmarked trees and residual vegetation shall be avoided to the extent feasible;

5. All trees shall be felled in line with the skidding direction wherever possible;

6. All trees shall be limbed on all sides where feasible and topped prior to skidding except where whole tree skidding is less disruptive to the forest resources;

7. Stumps shall be cut as low as can be done safely and to the extent that is feasible for harvesting equipment;

8. If stump removal will result in greater than three cubic yards of soil disturbance, a grading permit shall be obtained from TRPA prior to removal of stumps;

9. Green stumps shall be treated to prevent the spread of root disease as specified by a qualified forester; and

10. Insect-infested wood and wood susceptible to insect infestation shall be treated or disposed of as specified by a qualified forester.

B. Logging Roads, Skid Trails, and Landings

All logging roads, skid trails, and landings shall be constructed or otherwise created and maintained in accordance with the requirements of this chapter and the *Handbook of Best Management Practices*. Existing roads, skid trails, and landings shall be used whenever possible. New roads shall be approved only if TRPA finds that all alternatives have been explored and determines that the construction of new roads, skid trails, or landings would be the preferred alternative. In accordance with subparagraph 60.1.3.B, existing roads and landings may be accessed in the winter to help prepare for over-snow and over frozen ground tree removal. Such preparation for winter operations shall be limited to ~~packing snow over the roadways to obtain a firm snow base and~~ allowing movement of logs and equipment without disturbance of the soil. The standards provided below also shall apply.

1. The requirements and standards for design, grade, tree felling in right-of-way, slash cleanup, width, and maintenance, by road type as determined by TRPA, shall be as shown in Tables 61.1.6~~5~~-1 and 61.1.6~~5~~-2.

TABLE 61.1.6~~5~~-1: LOGGING ROADS AND SKID TRAILS: DESIGN AND GRADE

Road Type	Design	Maximum Grade
Permanent administrative roads	Plans and specifications	10%
Limited use roads remaining open	Plans and specifications	10% with occasional 15%
Limited use roads closed after logging	Plans and specifications	10% with occasional 15%
Temporary roads	Flag line	20%
Tractor ~~roads~~ and main skid trails	Flag line	~~30~~50%
Secondary skid trail	None	~~30~~50%

TABLE 61.1.6~~5~~-2: LOGGING ROADS AND SKID TRAILS: OTHER STANDARDS				
Road Type	**Right of Way Tree Falling**	**Minimum Slash Cleanup**	**Maximum Width**	**Maintenance**
Permanent administrative roads	Prefall	Removal within 50 feet of road	30 feet*	As determined by TRPA
Limited use roads remaining open	Prefall	Removal within 50 feet of road	15 feet 2/turnouts*	Annual maintenance required**
Limited use roads closed after logging	Prefall	Lop and scatter	15 feet 2/turnouts*	Close to vehicle use and revegetate
Temporary roads	Prefall	Lop and scatter	15 feet*	Close to vehicle use and revegetate
Tractor ~~roads~~ and main skid trails	Concurrent	Lop and scatter	15 feet	Close to vehicle use and revegetate
Secondary skid trails	Concurrent	Lop and scatter	15 feet	Close to vehicle use and revegetate

* Unless TRPA finds that greater width is necessary for feasible use or safety.

** "Annual Maintenance" includes activities such as restoring drainage features and making other road repairs as necessary.

2. Skid trails shall be located so as to protect residual stands through utilization of natural openings and topographic characteristics. The number of skid trails shall be kept to the minimum necessary and their width ~~shall be 15 feet or less~~ shall be the minimum size needed. Directional felling shall be used whenever possible to minimize skid trail density. Main skid trails shall be flagged in advance of felling operations ~~and shall require approval by TRPA~~.

3. Best Management Practices shall be installed on all skid trails, landings, and roads, no later than 15 days following completion of operations within a particular treatment unit, or at the time of seasonal shutdown, whichever is sooner.

4. Water breaks shall be spaced as provided below.

a. The maximum slope distance in feet by estimated hazard rating ~~land capability district~~ shall be according to Table 61.1.6~~5~~-3 unless exceptions to water break spacing are requested and approved by TRPA as equally or more protective of water quality.

~~TABLE 61.1.5-3: MAXIMUM SLOPE DISTANCE IN FEET BY LAND CAPABILITY DISTRICT~~		
~~**Gradient**~~	~~**5-7**~~	~~**3-4**~~
~~Less Than 10%~~	~~200~~	~~200~~
~~10 - 20%~~	~~150~~	~~90~~
~~21 - 30%~~	~~90~~	~~50~~

TABLE 61.1.6-3: WATER BREAK SPACING REQUIREMENTS BY ESTIMATED HAZARD RATING			
Estimated Hazard Rating	**U.S. Equivalent Measure Road or Trail Gradient (10 or less percent)**	**U.S. Equivalent Measure Road or Trail Gradient (11-25 percent)**	**U.S. Equivalent Measure Road or Trail Gradient (26-50 percent)**
Extreme	100 ft.	75 ft.	50 ft.
High	150 ft.	100 ft.	75 ft.
Moderate	200 ft.	150 ft.	100 ft.
Low	300 ft.	200 ft.	150 ft.

b. Water breaks shall be placed at lesser intervals as necessary to prevent soil erosion caused by firebreaks, trails, or landings.

c. Construction of water breaks shall be kept current with operations or at the time of seasonal shutdown, whichever is sooner. Erosion control work, including the design and interval of water breaks, shall require TRPA approval unless addressed under a Memorandum of Understanding.

d. Landing areas shall be properly drained in a manner to prevent soil erosion and stream pollution.

C. Removal Methods

Only the tree removal methods shown in Table 61.1.6~~5~~-4 shall be used on lands located within the land capability districts shown unless other removal methods are shown to have the same practical effect as removal methods below:

TABLE 61.1.6~~5~~-4: TREE REMOVAL METHODS	
Land Capability District	**Removal Method**
1a, 1c, or 2	Aerial removal, hand carry, and use of existing roads, in conformance with subsection 61.1.6. Over-snow and over frozen ground removal may be approved pursuant to subparagraph 61.1.6.F.1. Ground-based equipment and skidding may be used pursuant to 61.1.6.D.1. through 61.1.6.D.5. with approval by the TRPA.
1b (Stream Environment Zone)	As permitted in Land Capability District 1a, end lining may be approved when site conditions are dry and stable, or when winter conditions are adequate for end lining operations so as to avoid adverse impacts to the soil and vegetation. The use of "innovative technology" vehicles and/or "innovative techniques" for removing trees from SEZs may be considered pursuant to subparagraph ~~61.1.6.C.1.b.~~ 61.3.3.C.1.c.
3	As permitted in Land Capability District 1b, Ground skidding pursuant to subparagraph 61.1.6.D.~~F.2~~ may be approved.
4 - 7, Inclusive	As permitted in Land Capability District 1b. Ground skidding, as well as pickup and removal by conventional construction equipment, may be approved. Ground-based vehicle systems for removing trees without skidding may be approved pursuant to subparagraph 61.1.6.D~~F~~.5.

D. Skidding and Ground Based Vehicle Systems

Skidding is the act of dragging or partially suspending a tree or log along the ground, ~~or~~ snow, or frozen ground by cable systems or by mobile equipment. Ground skidding is the act of skidding a log or tree in full contact with the ground behind mobile equipment. End lining is dragging a log or tree in full contact with the ground by a winch. Cable yarding is the act of removing a log or tree by cable with one end of the log or tree in contact with the ground or fully suspended. Ground based vehicle systems include ~~are all in one "process at the stump"~~ harvesters and machines that cut, process, and remove trees and may require ~~without any~~ ground skidding.

1. Skidding over snow or frozen ground is preferred to unfrozen ground skidding. The depth of the snow shall be sufficient to prevent disturbance of the soil beneath the snow as determined by site-specific field observations. ~~Skidding operations shall cease when soil becomes visible on the surface of the snow.~~

2. Ground skidding may be permitted on slopes under 30%. Ground skidding on slopes between 30% and 50% requires TRPA review and approval to ensure that environmental protective measures (e.g., water breaks, vegetative buffers, slope length limitations, and remaining ground cover post-treatment, erodible soil avoidance) will be in place to minimize slope erosion~~.~~ ~~Ground skidding shall be limited to Land Capability Districts 3, 4, 5, 6, and 7.~~

3. Logs shall only be skidded endwise.

4. No logging arches, other than integral arch equipment, shall be permitted.

5. Ground-based vehicle systems for removing trees without skidding, such as harvester and forwarder combinations, may be used on slopes below 30 percent~~. approved by TRPA for use in Land Capability Districts 4, 5, 6, and 7~~. On slopes between 30% and 50%, ground-based vehicle systems for tree removal requires TRPA review and approval to ensure that environmental protective measures (e.g., water breaks, vegetative buffers, slope length limitations, and remaining ground cover post-treatment, erodible soil avoidance) will be in place to minimize slope erosion. The use of "innovative technology" vehicles and/or "innovative techniques" for removing trees without skidding may be considered in Land Capability District 1b and 3 pursuant to subparagraph 61.3.3.C.1.c.~~61.1.6.C.1~~ and subparagraph 61.1.6.C~~E~~.

E. Slash Disposal

Slash shall be disposed of according to an approved slash disposal plan.

1. Lop and scatter, pile and burn or broadcast burn (consistent with Sections 61.2 and 65.1), chip, or haul away. All burns shall be located beyond approved buffers from any stream channel, unless it can be demonstrated, using best available science, that slash burning within the approved buffer of a channel will not cause adverse environmental impacts.

2. Cull logs and other material shall be disposed of as required by the permit.

F. Erosion Control

The adequacy of all required BMPs shall be confirmed at the time of the TRPA pre-operations inspection. Any modifications to the required BMPs as determined by TRPA shall be incorporated into the project permit at that time or as determined to be necessary throughout forest management operations. The following erosion control standards apply:

1. The following Temporary BMPs are required to be installed prior to the commencement of any forest management or equipment operations:

   a. Temporary erosion controls and vegetation protection measures.

   b. Equipment exclusion area boundary markings or fencing, as necessary to comply with the TRPA-approved forest management plan.

2. Excavated material shall be stored upslope from the excavated areas to the extent possible. No material shall be stored in any SEZ, wet area, or stream buffer zone.

3. Projects must have design criteria to avoid tracking soil off the project site. Equipment operations shall cease when a violation of this condition exists. The site shall be cleaned and the road right-of-way swept clean when necessary.

4. No equipment or vehicle repairs, other than necessary maintenance of harvest equipment, shall be permitted in the project area unless authorized by TRPA. The discharge of petroleum products, construction waste and litter (including sawdust), or earthen materials to the surface waters of the Lake Tahoe Basin is prohibited. Spill containment and absorbent materials shall be kept on site at all times. All petroleum products and hazardous waste shall be removed from the project area and disposed of at an approved location.

61.1.7. Commercial Tree Removal

A. General Standard

Trees may be removed as a commercial enterprise pursuant to the tree removal practices of subsection 61.1.6.

B. Cutting and Cultivation of Christmas Trees

Legally existing Christmas tree cultivation operations, when certified by a qualified forester to be utilizing native species and proper silvicultural methods, may continue upon approval by TRPA. New Christmas tree farm operations meeting the above conditions may be permitted if TRPA finds them to be in compliance with the Code and the applicable plan area statements.

61.1.8. Substantial Tree Removal

Substantial tree removal shall be activities on project areas of three acres or more and proposing the removal of more than 100 live trees 14 inches dbh or larger, or proposing tree removal that as determined by TRPA after a joint inspection with appropriate state or federal Forestry staff does not meet the minimum acceptable stocking standards set forth in subparagraph 61.1.6.H. Substantial tree removal projects shall be processed by the appropriate state and federal agencies in coordination with TRPA as required below.

A. Private Parcels

The review process for private parcels shall include the following:

1. Harvest plan shall be written by a qualified forester;

2. Harvest plan shall be submitted to the appropriate state and federal agencies and TRPA with an initial environmental checklist or environmental assessment;

3. Preparation of environmental impact statement if necessary;

4. Pre-approval field review;

5. Approval of project by TRPA;

6. Pre-harvest field review; and

7. Post-harvest review.

B. Public Parcels

1. The review process for substantial tree removal for public parcels administered by public land management agencies may be determined according to a Memorandum of Understanding (MOU) between the partner agency and the TRPA. For agencies without an MOU with the TRPA, the process shall be the same as for private parcels listed above.

61.2. PRESCRIBED BURNING

61.2.1. Purpose

This section sets forth standards and regulations pertaining to the use of fire in controlled circumstances for vegetation management.

61.2.2. Applicability

The standards and regulations in this section apply to all intentional burning for the purpose of vegetation management, unless otherwise exempt from TRPA review under the provisions of Chapter 2: *Applicability of the Code of Ordinances*.

61.2.3. Prescribed Burning

A. Prescribed Burning Allowed

Persons who own or manage forests or range lands may use prescribed burning, consistent with the standards and regulations set forth in this section, to maintain forest health and diversity and to reduce the risk of wildfire.

61.2.4. Performance Standards

The use of prescribed burning for vegetation management shall comply with the standards provided below.

A. Location of Prescribed Burning

The use of prescribed burning shall be limited to those areas where the plan area statements designate as a permissible use one or more of the following uses:

1. Nonstructural wildlife habitat management;

2. Range improvement;

3. Fuels management; or

4. Prescribed fire management.

B. Extent of Prescribed Burning

Each prescribed burn shall be limited to the minimum area necessary to achieve the purpose of the prescription.

C. **Timing of Prescribed Burning**

Prescribed burning shall be limited to time periods for which TRPA finds that atmospheric conditions normally will allow complete dispersion of the smoke from the prescribed burn during each day of the burn.

D. **Responsible Persons**

A qualified expert, experienced in the use of fire for vegetation management, shall prepare a burning prescription for review and, if appropriate, approval by TRPA. The expert shall certify that the prescription meets the standards of this section. The expert shall oversee the conduct of the burn.

E. **Standards of Other Government Agencies**

All prescribed burning shall comply with applicable standards of other government agencies with appropriate jurisdiction, including but not limited to the following agencies: the El Dorado County Air Pollution Control District; the Placer County Air Pollution Control District; the California Air Resources Board; the California State Water Resources Control Board; the California Regional Water Quality Control Board; the Nevada Division of Environmental Protection; the California and Nevada Departments of Forestry; and the United States Forest Service. Where TRPA standards conflict with another agency's standards, the most stringent standard shall control.

61.2.5. Compliance Program

To achieve compliance with the standards in subsection 61.2.4, TRPA shall apply the following provisions:

A. **Consistency with Primary Use**

TRPA shall review and, if appropriate, approve applications to conduct prescribed burns consistent with the provisions of Chapter 21: *Permissible Uses*, regarding allowed and special uses for those uses listed in subparagraph 61.2.4.A.

B. **Burn Prescription**

All applications to conduct prescribed burning shall be accompanied by a burn prescription. A burn prescription shall include the following items:

1. Detailed statement of the purpose of the prescribed burn;

2. Description, including a map at an appropriate scale of the location and a real extent of the prescribed burn. Such description shall allow TRPA to determine whether the proposed burn complies with subparagraphs 61.2.4.A and 61.2.4.B;

3. Description of the timing of the prescribed burn, and meteorological information that demonstrates that the timing of the prescribed burn will normally allow complete dispersion of the smoke from the burn during each day of the burn;

4. A list of the applicable standards of TRPA and other government agencies with jurisdiction over the burn, and a discussion of how the proposed prescription complies with those standards;

5. A detailed description of the proposed burning operation, including a description of all safety procedures that will be used to prevent wildfire;

6. A certification by a qualified expert experienced in the use of fire for vegetation management that the burn prescription complies with this

section; and that the expert shall oversee the conduct of the burn to ensure that the prescription is followed; and

61.3. VEGETATION PROTECTION AND MANAGEMENT

61.3.1. Purpose

In accordance with the Vegetation Conservation Element of the Regional Plan Goals and Policies, this section provides for the protection of Stream Environment Zone (SEZ) vegetation, other common vegetation, uncommon vegetation, and sensitive plants. It also provides for remedial management of vegetation to achieve and maintain environmental thresholds for plant species and structural diversity, and the maintenance of vegetation health. The management and protection of vegetation shall, at a minimum, consider the diversity of plant species and landscape pattern of plant communities, and their attributes in relationship to wildlife and fisheries habitat, scenic quality, recreation use, soil conservation, and water quality.

61.3.2. Applicability

TRPA requires the protection and maintenance of all native vegetation types. TRPA may require the preparation and implementation of a remedial vegetation management plan for any parcel where the need for remedial vegetation management has been identified for purposes of environmental threshold maintenance or attainment.

61.3.3. Protection of Stream Environment Zones

A. General Requirement

Unless excepted in B below, no project or activity shall be undertaken in an SEZ (Land Capability District 1b) that converts SEZ vegetation to a non-native or artificial state or that negatively impacts SEZ vegetation through action including, but not limited to, reducing biomass, removing vegetation, or altering vegetation composition.

B. Exceptions

The activities below are exceptions to the general requirement in A above.

1. Manipulation or management of SEZ vegetation may be permitted in accordance with the Code for purposes of SEZ vegetation health or wildlife or fish habitat improvements, and after approval of a vegetation management plan pursuant to subparagraph 61.3.5.B, or as provided in Section 30.5, subsection 30.4.4, subparagraph 30.4.6.D.3, Section 63.3, or Sections 61.1 or 61.2.

2. Maintenance of landscaping that was installed prior to the creation of TRPA, or installed for the purpose of scenic quality pursuant to Chapter 36: *Design Standards*, or pursuant to a TRPA permit, or under a TRPA exemption prior to August 1, 1997, provided that fertilizer use is restricted in accordance with the BMP Handbook and described in subparagraph 60.1.8.A, unless a remedial action pursuant to subsection 61.3.4 has been taken by TRPA.

3. Removal of vegetation may be permitted pursuant to subparagraphs 2.3.2.E, or 2.3.6.A.8, Section 33.6, Chapter 64: *Livestock Grazing*, or under defensible-space guidelines approved by TRPA.

C. Tree Cutting Within Stream Environment Zones

Tree cutting within stream environment zones may be permitted to allow for early successional stage vegetation management, sanitation salvage cuts, fuels management for fire hazard reduction, maintenance of utility rights-of-way, restoration or enhancement of ecosystem health and diversity, and fish and wildlife habitat improvement projects, in accordance with the standards provided below. TRPA -approved reasons for removal of trees over 30 inches dbh in westside forest types and larger than 24 inches dbh in eastside forest types within an SEZ are the same as TRPA-approved reasons for removal of trees over 30 inches dbh in westside forest types and larger than 24 inches dbh in eastside forest types as listed in Sections 61.3.7.A.1 through Section 61.3.7.A.10.

1. Vehicle Restrictions

All vehicles shall be restricted to areas outside of the SEZ or to existing roads within SEZs, except for tree removal over-snow or frozen ground with hard frozen soil conditions or use of low impact technology where permanent disturbance does not occur.

The following criteria shall apply:

a. TRPA may permit the use of vehicles in/on frozen ground with hard frozen soil conditions or over-snow tree removal operations. A qualified forester will ensure that conditions are suitable to prevent visible or permanent soil disturbance and/or significant vegetation damage; and

b. Winter ground-based equipment operations would take place on portions of the treatment unit where adequate snow or frozen ground with hard frozen soil conditions are present. The following criteria will be applied in determining equipment operations:

(i) Frozen soil operations are permitted where operated vehicles, tractors and equipment can travel without sinking into soil, road, and/ or landing surfaces to a depth of more than 2 inches for a distance of more than 25 feet. Temperatures must also remain low enough to preclude thawing of the soil surface.

(ii) For over-snow operations, maintain approximately 12 inches of compacted snow/ice on undisturbed ground, and 6 inches of compacted snow/ice on existing disturbed surfaces. For over-the-snow and frozen soil operations in SEZs, exclude ground- based equipment from the 25- foot buffer around perennial and intermittent watercourse channels.

c. TRPA shall review site-specific proposals for and may permit the use of "innovative technology" vehicles and/or "innovative techniques" for the purpose of fire hazard reduction in SEZs provided that no significant soil disturbance or significant vegetation damage will result from the use of equipment. (See Chapter 90: *Definitions*, for definitions of "innovative technology" vehicles and "innovative techniques.") Project proposals should be developed within an adaptive management framework that will result in data that can be used to support and/or improve on equipment and techniques. TRPA shall conduct a pre-operation inspection of the site to decide if vehicle use is appropriate for the given situation, to verify the boundaries of the SEZ, and to identify other areas of concern. The following minimum conditions shall apply:

(i) Project proponents shall provide documentation substantiating that the use of such vehicles will not cause significant soil disturbance or significant vegetation damage. Documentation must take into account soil types, hydrology, vegetation type and cover, and other ecosystem characteristics, relevant to the use of such vehicles in similar environments. Documentation can include relevant scientific research, monitoring studies, and other supporting analyses;

(ii) Operations using "innovative technology" vehicles in SEZs shall be limited to the management of common conifer species (e.g., lodgepole pine, white fir), however, incidental hardwoods that need to be removed from within a conifer vegetation type may also be removed using the vehicles;

(iii) Operations shall be limited to times of the year when soils are sufficiently dry to avoid and/or minimize compaction and sufficiently stable to avoid and/or minimize erosion;

(iv) Erosion control measures (BMPs) shall be implemented both during and after operations to avoid soil detachment and transport wherever possible, and to minimize erosion wherever soil disturbance cannot be avoided;

(v) To prevent sediment delivery to surface waters, including wetlands, more stringent setbacks from watercourses than the setbacks set forth in other regulations regulating timber harvests, such as the California Forest Practice Rules and Nevada State Statutes, may be designated if deemed necessary by TRPA;

(vi) Operations shall incorporate appropriate measures to avoid impacts to wildlife during critical wildlife nesting and denning periods in accordance with Chapter 62: *Wildlife Resources*;

(vii) Operations shall incorporate measures to protect historic resources in accordance with Chapter 67: *Historic Resource Protection*; and

(viii) Projects shall be monitored to ensure that the SEZ has not sustained any significant damage to soil or vegetation function. Along with the project proposal, adaptive management concepts should be applied to the monitoring plan. A monitoring plan shall be submitted with all project proposals, including at a minimum: a list of sites and attributes to be monitored; specification of who will be responsible for conducting the monitoring and reporting; a narrative for implementing corrective actions when monitoring determines such corrective action is necessary; and a monitoring and reporting schedule.

(ix) Once an innovative technology has been deemed acceptable by TRPA, all partners or permittees may utilize that technology.

2. Soil Conditions

All work within stream environment zones shall be limited to times of the year when soil conditions are dry and stable, or when conditions are adequate for frozen ground with hard frozen soil conditions or over-snow tree removal operations without causing significant soil disturbance and/or significant vegetation damage

3. Trees and Debris Kept from Streams

Felled trees and harvest debris shall be kept out of all watercourses. If deposited in the stream, the material shall be promptly removed unless it is determined that such logs and woody material adds structural diversity pursuant to fish and wildlife habitat improvements in accordance with Chapter 62: *Wildlife Resources*, and Chapter 63: *Fish Resources*. This determination shall be approved by TRPA. Logs or other woody material may be placed in streams to provide woody structure pursuant to fish or wildlife habitat improvement programs approved by TRPA in accordance with Chapter 63.

4. **Stream Crossings**
The crossing of perennial streams or other wet areas shall be limited to improved crossings meeting Best Management Practices or to temporary bridge spans that can be removed upon project completion or at the end of the work season, whichever is sooner. Any damage or disturbance to the stream environment zone associated with a temporary crossing shall be restored within one year of its removal. In no instance shall any method requiring the placing of rock and earthen material into the stream or streambed be considered an improved crossing. Other temporary measures may be permitted for dry stream crossings in accordance with the *Handbook of Best Management Practices*.

5. **Special Conditions**
Special conditions shall be placed on all tree harvests within stream environment zones or within the transition or edge zone adjoining stream environment zones, as necessary to protect in-stream aquatic habitat values and wildlife habitat integrity and diversity.

61.3.4. Remedial Vegetation Management

TRPA and resource management agencies, including the states' forestry departments, shall identify areas where remedial management of vegetation is necessary to achieve and maintain environmental thresholds for health and diversity in vegetation. Requests by TRPA to prepare and implement a remedial vegetation management plan for a specified area shall follow the procedures set forth in Section 5.12: *Remedial Action Plans*.

61.3.5. Preparation of Remedial Vegetation Management Plans

At the request of TRPA, remedial vegetation management plans shall be prepared by the property owners of areas identified for remedial vegetation management in cooperation with TRPA and appropriate resource management agencies.

A. Plan Content
Remedial vegetation management plans shall contain, at a minimum, the following information:

1. Purpose of the management plan, including a list of objectives;
2. Description of existing vegetation, including the abundance, distribution, and age class of tree species;
3. Remedial measures necessary to achieve the stated objectives, including details of harvest and revegetation plans (see Section 61.4); and
4. An implementation schedule, including a monitoring program to report progress on monitoring of vegetation.

B. **Plan Approval**

TRPA may approve a remedial vegetation management plan provided the plan is necessary to achieve, and can reasonably be expected to achieve, the purposes set forth in subsection 61.3.4.

61.3.6. Sensitive and Uncommon Plant Protection and Fire Hazard Reduction

A. **Purpose**

This subsection sets forth standards for the preservation and management of vegetation of significant scenic, recreational, educational, scientific, or natural values of the region, and for management of vegetation to prevent the spread of wildfire.

B. **Applicability**

This subsection applies to all projects and activities that could have a detrimental effect on designated sensitive plants or uncommon plant communities, and to all areas where vegetation may contribute to a significant fire hazard.

C. **Sensitive Plants and Uncommon Plant Communities**

Designation of plants for special significance is based on such values as scarcity and uniqueness. The following standards shall apply to all sensitive plants and uncommon plant communities referenced in the environmental thresholds, and to other plants or plant communities identified later for such distinction. The general locations of sensitive plant habitat and uncommon plant communities are depicted on the TRPA Special Species map layers. The special species map layers indicate the location of habitat for threatened, endangered, rare, and special interest species and where populations of sensitive or uncommon plants have been observed.

1. **Sensitive Plants**

a. **List of Sensitive Plants**

The sensitive plants are:

(i) Rorippa subumbellata (Tahoe yellow cress);

(ii) Arabis rigidissima var. demote (Galena Creek rock cress);

(iii) Lewisia longipetala (long-petaled lewisia);

(iv) Draba asterophora v. macrocarpa (Cup Lake draba); and

(v) Draba asterophora v. asterophora (Tahoe draba).

b. **Standards for Sensitive Plants**

Projects and activities in the vicinity of sensitive plants or their associated habitat shall be regulated to preserve sensitive plants and their habitat. All projects or activities that are likely to harm, destroy, or otherwise jeopardize sensitive plants or their habitat shall fully mitigate their significant adverse effects. Projects and activities that cannot fully mitigate their significant adverse effects are prohibited. Measures to protect sensitive plants and their habitat include, but are not limited to:

(i) Fencing to enclose individual populations or habitat;

(ii) Restrictions on access or intensity of use;

(iii) Modifications to project design as necessary to avoid adverse impacts;

(iv) Dedication of open space to include entire areas of suitable habitat; or

(v) Restoration of disturbed habitat.

2. **Uncommon Plant Communities**

a. **List of Uncommon Plant Communities**
The uncommon plant communities are:

(i) The deepwater plants of Lake Tahoe, Grass Lake (sphagnum fen);

(ii) Osgood Swamp, Hell Hole (sphagnum fen);

(iii) Pope Marsh, Taylor Creek Marsh, Upper Truckee Marsh; and

(iv) The Freel Peak cushion plant community.

b. **Standards for Uncommon Plant Communities**
Uncommon plant communities shall be managed and protected to preserve their unique ecological attributes and other associated values. Projects and activities that significantly adversely impact uncommon plant communities, such that normal ecological functions or natural qualities of the community are impaired, shall not be approved.

D. Vegetation Management to Prevent the Spread of Wildfire

Within areas of significant fire hazard, as determined by local, state, or federal fire agencies, flammable or other combustible vegetation shall be removed, thinned, or manipulated in accordance with local and state law. Revegetation with approved species or other means of erosion control including soil stabilization may be required where vegetative ground cover has been eliminated or where erosion problems may occur.

61.3.7. Old Growth Enhancement and Protection

The standards in this subsection shall govern forest management activities and projects.

A. Standards for Conservation and Recreation Lands

Within lands classified by TRPA as conservation or recreation land use, any live, dead, or dying tree larger than 30 inches diameter at breast height (dbh) in westside forest types shall not be cut, and any live, dead or dying tree larger than 24 inches diameter at breast height in eastside forest types shall not be cut, except as provided below.

1. **Unreasonably Contribute to Fire Hazard**
Trees and snags larger than 30 inches dbh in the westside forest types and larger than 24 inches dbh in eastside forest types may be felled, treated, or removed in urban interface areas if TRPA determines that they would unreasonably contribute to fuel conditions that would pose a fire threat or hinder defense from fire in an urbanized area. Within the urban interface areas, fire management strategies favoring the retention of healthy trees larger than 30 inches dbh in the westside forest types and larger than 24 inches dbh in eastside forest types trees shall be fully considered. Urban interface areas are defined as all undeveloped lands within a 1,250 foot zone immediately adjacent to TRPA residential, commercial, or public service plan area boundaries.

2. **Unacceptable Risk to Structures or Areas of High Use**
A tree larger than 30 inches dbh in westside forest types and larger than 24 inches dbh in eastside forest types may be felled, treated, or removed

if TRPA and the land manager determine the tree poses an unacceptable risk to occupied or substantial structures, overhead utility lines and conductors, critical public or private infrastructure, or areas of high human use. Examples of areas of high human use are campgrounds, parking lots, ski trails, and developed beaches. Where a land manager determines that a tree constitutes a physical emergency (e.g., imminent threat of falling on occupied or substantial structures, or people), the land manager may remove the tree but must provide photographic documentation and any applicable paperwork and fees to TRPA within ten working days of removal of the hazardous tree.

3. **Diseased or Infested Trees**
Where immediate treatment and removal is warranted to help control an outbreak of pests or disease, severely insect-infested or diseased trees larger than 30 inches dbh in westside forest types and larger than 24 inches dbh in eastside forest types may be removed. Trees to be felled, treated, or removed require TRPA review on a project-level basis, within 30 working days of written notification by the land manager.

4. **Ecosystem Management Goals**
In limited cases, trees larger than 30 inches dbh in the westside forest types and larger than 24 inches dbh in eastside forest types may be felled, treated, or removed if a management prescription clearly demonstrates that the identified trees need to be cut for ecosystem management goals consistent with TRPA goals and policies and to increase forest health and resilience. The project and prescription must be developed and reviewed by a qualified forester, and only the trees necessary to achieve ecosystem objectives at a specific site shall be removed. Each tree larger than 30 inches dbh in the westside forest types and larger than 24 inches dbh in eastside forest types shall be approved by TRPA. The marking of these trees shall be done by a qualified forester.

5. **Ski Areas Master Plans**
In ski areas with existing TRPA-approved master plans, trees larger than 30 inches dbh in the westside forest types and larger than 24 inches dbh in eastside forest types may be removed for facilities that are consistent with that master plan. For activities that are consistent with a TRPA – approved master plan, trees larger than 30 inches dbh in the westside forest types and larger than 24 inches dbh in eastside forest types may be removed when it is demonstrated that the removal is necessary for the activity.

6. **EIP Projects**
Trees larger than 30 inches dbh in the westside forest types and larger than 24 inches dbh in eastside forest types may be removed when it is demonstrated that the removal is necessary for the activity.

7. **Extreme Fuel Loading**
In case of extreme fuel loading some snags larger than 30 inches dbh in the westside forest types and larger than 24 inches dbh in eastside forest types may be cut if the removal is consistent with subsection 62.3.4: Snags and Coarse Woody Debris.

8. **Large Public Utilities Projects**
Trees larger than 30 inches dbh in westside forest types and larger than 24 inches dbh in eastside forest types may be removed for large public utilities projects if TRPA finds there is no other reasonable alternative.

9. **Emergency Fire Suppression**
Trees may be removed when an emergency fire suppression need exists as determined by the local, state, or federal fire suppression agency involved in a fire suppression activity.

10. **Private Landowners**
Private landowners may fell, treat, or remove trees larger than 30 inches dbh in the westside forest types and larger than 24 inches dbh in eastside forest types provided the landowner follows one of the planning processes set forth in subparagraph C.

B. **Standards for Non-SEZ Urban Lands**

Within non-SEZ urban areas, individual trees larger than 30 inches dbh that are healthy and structurally sound shall be retained as desirable specimen trees having aesthetic and wildlife value, unless no reasonable alternative exists to retain the tree, including reduction of parking areas or modification of the original design.

C. **Alternative Private Landowner Process**

As an alternative to complying with the standards in subparagraph A, a private landowner may follow one of the following planning processes to achieve or maintain the late seral/old growth threshold, goals, and polices.

1. **Alternative Forest Management Plan**
A private landowner, in the development of a forest management plan, shall follow the planning process described in Chapter 14: *Specific and Master Plans*, except as provided below.

    a. In relation to subparagraph 14.8.1.A only the private landowner may initiate the private forest management planning process.

    b. In relation to subparagraph 14.8.1.B the project team shall consist of a designee of the Executive Director, appropriate regulatory and land management agencies, the proponent's qualified forester, and the team shall consult with the appropriate public land management agencies if the private land is adjacent to public land.

    c. In relation to Section 14.9, the content of a forest master plan shall be described in the TRPA Forest Master Plan Guidelines. The content shall include enough information to make the required findings of Section 14.10; shall provide guidelines for salvage harvest, insect control, and fire salvage. The document shall be organized by described and mapped planning units. As an example, a non-industrial timber management plan that contains enough information to make the required findings of Section 14.10 can be submitted provided it is developed with approval of the steering committee.

    d. The harvest practices shall comply with local and state regulations.

    e. A proposed schedule (and seasonality) of harvest projects and improvement projects shall be included within the plan.

    f. Individual harvest projects proposed under the master plan within the planned schedule and proposed method shall receive a streamlined review.

2. **Limited Forest Plan**
Private landowners may prepare a limited forest plan when there would be limited proposed impact to large trees.

a. A limited forest plan may be prepared if ten percent or less of the trees larger than 30 inches dbh in the westside forest types and larger than 24 inches dbh in eastside forest types within the project site are proposed to be cut within the life of the plan.

b. The limited forest plan shall include:

(i) The relative state permit application, if available;

(ii) Description of harvest activities;

(iii) Description of management activities;

(iv) Explanation of how thresholds, goals and policies shall be attained under the forest plan; and

(v) The expiration date of the plan. A minimum lifespan of ten years and a maximum lifespan of 50 years shall be accepted.

3. TRPA shall review proposed cutting of trees larger than 30 inches dbh in the westside forest types and larger than 24 inches dbh in eastside or larger forest types on a tree-by-tree basis consistent with the forest plan.

61.3.8. Historic and Cultural Resource Protection

A. Operations and any ground disturbing activities shall be in accordance with Chapter 67: *Historic Resource Protection*. All historic resources located within the project area shall be flagged and avoided except in accordance with a TRPA-approved resource recovery plan. Flagging shall be removed at the time of completion of operations.

61.3.9. Wildlife, Habitat, and Sensitive Plants

A. Operations shall incorporate appropriate measures to avoid impacts to wildlife during critical wildlife nesting and denning periods in accordance with Chapter 62: Wildlife Resources.

B. Snags shall be retained in accordance with subsection 62.3.4.

C. Discovery of a TRPA-designated sensitive species or species of interest, or the location of a nest or den of one of those species, shall be immediately reported to TRPA. Any nests, dens, or plant locations shall be protected in accordance with TRPA regulations. All work within the project area shall cease until TRPA identifies under what conditions the project may continue.

61.4. REVEGETATION

61.4.1. Purpose

This section provides standards for revegetation for such purposes as soil stabilization and improvement of the vegetative cover mix.

61.4.2. Applicability

This section shall apply wherever revegetation is required as a condition of project approval or where revegetation is necessary to comply with other provisions of the Code. Landscaping provisions are set forth in Chapter 36: *Design Standards*.

61.4.3. Approved Species

Revegetation programs shall use TRPA-approved plant species listed on the TRPA Recommended Native and Adapted Plant List. This list shall be a part of the *Handbook of Best Management Practices* and shall be updated from time to time based on the criteria that listed plants should be adapted to the climate of the Tahoe region, should require little water and fertilizer after establishment, and should be non-invasive. Specifications of plant materials shall be in accordance with the following requirements:

A. Site Conditions
Plant species selected shall be appropriate for site conditions.

B. Small Scale Programs
Small scale revegetation programs shall emphasize the use of TRPA-approved grass species in conjunction with mulching or other temporary soil stabilization treatments, as described in the *Handbook of Best Management Practices*.

C. Large Disturbed Areas
Revegetation of disturbed areas larger than 10,000 square feet shall include reseeding with TRPA-approved grass species as well as reestablishment of appropriate shrub and tree species.

D. Fertilizer
Fertilizer may be permitted to help establish vegetation following planting, but plant species shall be selected that do not require long term fertilization.

61.4.4. Soil Stabilization

Site preparation for revegetation shall include measures necessary to stabilize the soil until the vegetation is reestablished. Revegetation and stabilization programs for disturbed sites shall minimize the use of extensive grading whenever practical. Situations where extensive grading and recontouring may be necessary include the following:

A. Oversteepened cut slopes;

B. Quarry sites;

C. Abandoned landfills;

D. Reclamation of already developed sites; or

E. Abandoned roads.

61.4.5. Revegetation Plans

Where revegetation is required to stabilize soils, replace removed vegetation, or for rehabilitation of areas where runoff or soil erosion needs to be controlled, the applicant shall provide a revegetation plan.

A. Contents of Plan
Revegetation plans shall include at a minimum:

1. A description of the site, including the soil type, if applicable, the stream environment zone or backshore type, and existing vegetation;
2. A list of appropriate plant species to be used at the site and a plan showing where they will be planted;
3. The number and size of shrubs and trees to be used, if any;
4. A description of the extent and methods of irrigation, if any;
5. Specifications for site preparation and installation of plant materials;

6. Specifications and schedule for onsite care, including amount and method of application of fertilizers pursuant to the *Handbook of Best Management Practices*, if necessary;

7. Specifications for long term plant care and protection, including the amount and method of application of fertilizers, if necessary; and

8. A description of mulches or tackifiers to be used.

B. **Plant Materials**

Plant materials to be used in a stream environment zone or the backshore shall be from the list shall be derived from stock possessing genetic characteristics of native plants or, if used outside of these areas, plant materials shall originate from a similar elevation and climate as the revegetation site if stock is available. If such stock is not available, stock with demonstrated success in the region may be approved.

C. **Soil Materials**

Revegetation plans may include provisions that allow for the importation of soil in limited situations involving reclamation of extensively disturbed sites, such as those in subsection 61.4.4. Soil material may be permitted to be imported from outside the region if an acceptable source in the region cannot be located. Acceptable sources of soil material in the region include by-products of approved dredging or grading activities and compost.

D. **Security Release**

The portion of a security related to revegetation shall be released when TRPA determines that the required vegetation is established. Establishment of vegetation generally takes one or two growing seasons.

Attachment B

Required Findings/Rationale

ATTACHMENT B

REQUIRED FINDINGS / RATIONALE

TRPA Code of Ordinances Section 3. 3 – Determination of Need to Prepare an Environmental Impact Statement

Finding: TRPA finds that the proposed Code amendments will not have a significant effect on the environment.

Rationale: An Initial Environmental Checklist (IEC) has been prepared to evaluate the effects of the proposed amendments to the Code of Ordinances (see Attachment C). The IEC found that the proposed Code amendments would not have a significant effect on the environment.

The proposed amendments are consistent with and will implement Chapter 61 Vegetation and Forest Health. The amendments are not anticipated to result in significant environmental impacts. As demonstrated in the accompanying findings, amendments to Chapter 61 Vegetation and Forest Health will not result in an unmitigated significant impact on the environment or cause the environmental threshold carrying capacities to be exceeded.

TRPA Code of Ordinances Section 4. 4 – Threshold-Related Findings

1. Finding: The amendments to the Code of Ordinances are consistent with and will not adversely affect implementation of the Regional Plan, including all applicable Goals and Policies, plan area statements and maps, the Code, and other TRPA plans and programs;

Rationale: The proposed code amendments will not have significant environmental impacts and will increase forest resilience while decreasing fire risk in the Tahoe Basin. The Code amendments are consistent with the Regional Plan policies and goals and all implementing elements of the Regional Plan.

2. Finding: The proposed amendments will not cause the environmental threshold carrying capacities to be exceeded; and

Rationale: The proposed amendments are consistent with the threshold attainment strategies in the Regional Plan. As demonstrated in the findings , these amendments will not cause the environmental threshold carrying capacities to be exceeded.

3. Finding: Wherever federal, state, or local air and water quality standards apply for the region, the strictest standards shall be attained, maintained, or exceeded pursuant to Article V(d) of the Tahoe Regional Planning Compact.

Rationale: The proposed amendments would not adversely affect any state, federal, or local standards. The amendments are intended to allow implementors opportunity to increase pace and scale of treatment, decrease fire risk, and increase forest resilience in the face of climate change, insects and disease, and drought.

TRPA Code of Ordinances Section 4. 6 – Findings Necessary to Amend or Adopt TRPA Ordinances, Rules, or Other TRPA Plans and Programs.

Finding: The Regional Plan and all of its elements, as implemented through the Code, Rules, and other TRPA plans and programs, as amended, achieves and maintains thresholds.

Rationale: As discussed within Sections 4.4. and 4.5 above, the Regional Plan and all of its elements, as amended, achieves and maintains thresholds. The proposed amendments will improve the implementation of threshold attainment by improving forest resilience and health and decreasing high severity fire risk.

Attachment C

Initial Environmental Checklist (IEC)

Project Name: Proposed Code Amendments: Allowing Ground-based Mechanical Equipment on Slopes between 30 and 50 percent.

Project Description:

The Angora Fire began in the North Upper Truckee area in South Lake Tahoe, California. The fire burned out of control, threatening hundreds of residences and commercial structures, and resulted in thousands of evacuations. A total of 3,100 acres were burned and 254 homes were destroyed. The Angora Fire underscored the need for a comprehensive review of fire prevention and fuels management practices in the Basin and spurred the creation of the Joint Fire Commission to conduct this review and generate recommendations on future policy and practice.

The Emergency California-Nevada Tahoe Basin Fire Commission Report, produced in 2008, created a set of findings and recommendations presented in six categories that address both short and long-term needs, policy changes, education, funding, governmental structures, and environmental practices related to Lake Tahoe's vulnerability to wildfire.

The Commission found that when the TRPA was created the risk of catastrophic wildfire to ecosystems and communities was not considered. This risk is compounded by climate change that ushers in a new era of "mega-fires". Subsequently, the Commission recommended the TRPA, LRWQCB, USDA Forest Service, and other affected agencies amend their plans and ordinances to allow for mechanical equipment use on slopes greater than 30% based on current and future technology and forest practices that ensure environmental protection.

Article 4 of the California Forest Practice Act allows for mechanical treatment on slopes up to 50%. The Act states: "Except for tethered operations, heavy equipment shall be prohibited where any of the following conditions are present: (A) Slopes steeper than 65%. (B) Slopes steeper than 50% where the Erosion Hazard Rating is high or extreme."

In Nevada, NRS Chapter 528 Forest Practice and Reforestation also allows mechanical treatments on steep slopes through a variance procedure with the Nevada Firewarden. When issuing a variance, the Firewarden will consider whether ground-based equipment may destroy advanced regeneration and litter cover; the extent to which ground-based equipment may cause soils to be displaced or erode; and, the extent to which ground-based equipment may cause siltation and eroded soils to infiltrate the 50-foot stream buffer.

Likewise, The LTBMU 2016 Land Management Plan outlines a series of standard and guidelines related to forest vegetation, fuels, and fire management. Standard and Guideline 30 outlines the following for forest treatments, "In general, operate ground-based mechanized equipment for vegetation treatment on slopes less than or equal to 30%. Exceptions should be consistent with safety and design specifications and with the ability to effectively alleviate significant resource impacts."

The project proposes ground-based mechanical equipment for thinning treatments on slopes up to 50 percent, which increases the proportion of land in the Basin that could be treated using mechanical equipment (see Table 1 and Figure 1). Chapter 61 of the TRPA Code prohibits mechanized equipment on slopes greater than 30 percent. The proposed project includes an amendment to the TRPA Code to allow ground-based mechanical equipment and skidding on slopes up to 50 percent depending on specific site conditions and TRPA approval.

Approximately 60,685.05 acres within the Basin are located on slopes between 30 and 50 percent. Currently, under the TRPA Code of Ordinances, these acres may only be treated by hand with subsequent pile burning or aerial logging. Allowing ground-based mechanical equipment as opposed to hand thinning on slopes up to 50 percent would allow land managers to remove trees to meet restoration objectives, increase forest resilience, and decrease fire risk. Approximately, 25,305.05 acres (41.7%) on slopes between 30 and 50 percent fall within the Wildland Urban Interface

(WUI) Threat or Defense Zones (Figure 2). A WUI Defense Zone is the area directly adjoining structures and evacuation routes that is converted to a less-flammable state to increase defensible space and firefighter safety. The WUI Threat Zone is an additional strip of vegetation modified to reduce flame heights and radiant heat. These areas represent critical acres for treatment in the face of climate change and longer, more extreme fire seasons. Additionally, the code amendment may increase the pace and scale of thinning treatments and generate financial and ecological efficiencies by utilizing staff capacity and equipment more effectively for planning and implementation of restoration treatments such as mechanical thinning and broadcast burning.

As noted above, allowing ground-based mechanical equipment on slopes between 30 and 50 percent would likely decrease the number of hand piles for burning. This would allow managers to reduce smoke emissions associated with pile burning and increase opportunities for biomass utilization that could provide long-term carbon storage and reduce greenhouse gas emissions.

The Code amendment would not allow the use of ground-based mechanical equipment on slopes up to 50 percent slopes that are identified or mapped as unstable or active or dormant landslides.

The proposed code amendments will require TRPA review and approval of ground skidding and ground-based mechanical equipment operations on slopes between 30 and 50 percent to ensure environmental protective measures will be in place to minimize slope erosion. Project-specific requirements to meet minimized slope erosion can include but are not limited to leaving remaining ground cover above 85%, use of slash mats, use of low-pressure technology that limits ground disturbance, or inclusion of vegetative buffers. Prior to approval and implementation, implementors will submit to the TRPA their project description, information, and an initial environmental checklist per project that demonstrates minimized slope erosion.

The Basin-wide Code amendment would apply to approximately 60,685.05 acres within the Basin (see Figure 1). Potential for access constraints among other site-specific factors (e.g., unstable slopes) would inform where mechanical treatments would be appropriate and feasible on 30-50 percent slopes. Of the 60,685.05 acres within the Basin that are on slopes between 30 to 50 percent, approximately 47,162.44 acres (77.7%) are on federal lands, 5,270.12. acres (8.6%) are on state lands, 3,885.40 acres are on private lands, and 882.28 acres are on local lands (Table 2 and Figure 3). Partner agencies that would be able to utilize this code amendment include the USDA Forest Service, the California Tahoe Conservancy, the Nevada Division of Forestry, The Nevada Division of State Lands, California State Parks, and others.

Approximately, 6,293.77 acres within the Basin are on slopes between 30 to 50 percent and are also classified as Wilderness. This is a National Forest System classification that allows for limited management and does not allow mechanized equipment unless under emergency authorizations. Wilderness areas within the Basin are at higher elevations with less trees and more exposed granite, so will most likely not warrant mechanical treatment.

Approximately, 362.83 acres within the Basin are on slopes between 30 to 50 percent and are classified as Stream Environment Zones (SEZs). These areas are not included in the potential code amendment.

Table 1: Acreage by Slopes in the Lake Tahoe Basin

Area	0-30% Slopes (acres)	30-50% Slopes (acres)	Slopes >50% (acres)	Total (acres)
Lake Tahoe Basin	121,536.1	60,685.05	44,142.56	226,363.61

Table 2: 30 to 50 Percent Slopes Acreage by Ownership

Ownership	30-50% Slopes (acres)
Federal	47,162.44
Local	882.28
Private	3,885.40
State	5,270.12
Other	3,592.04

Figure 1: Lake Tahoe Basin Slopes

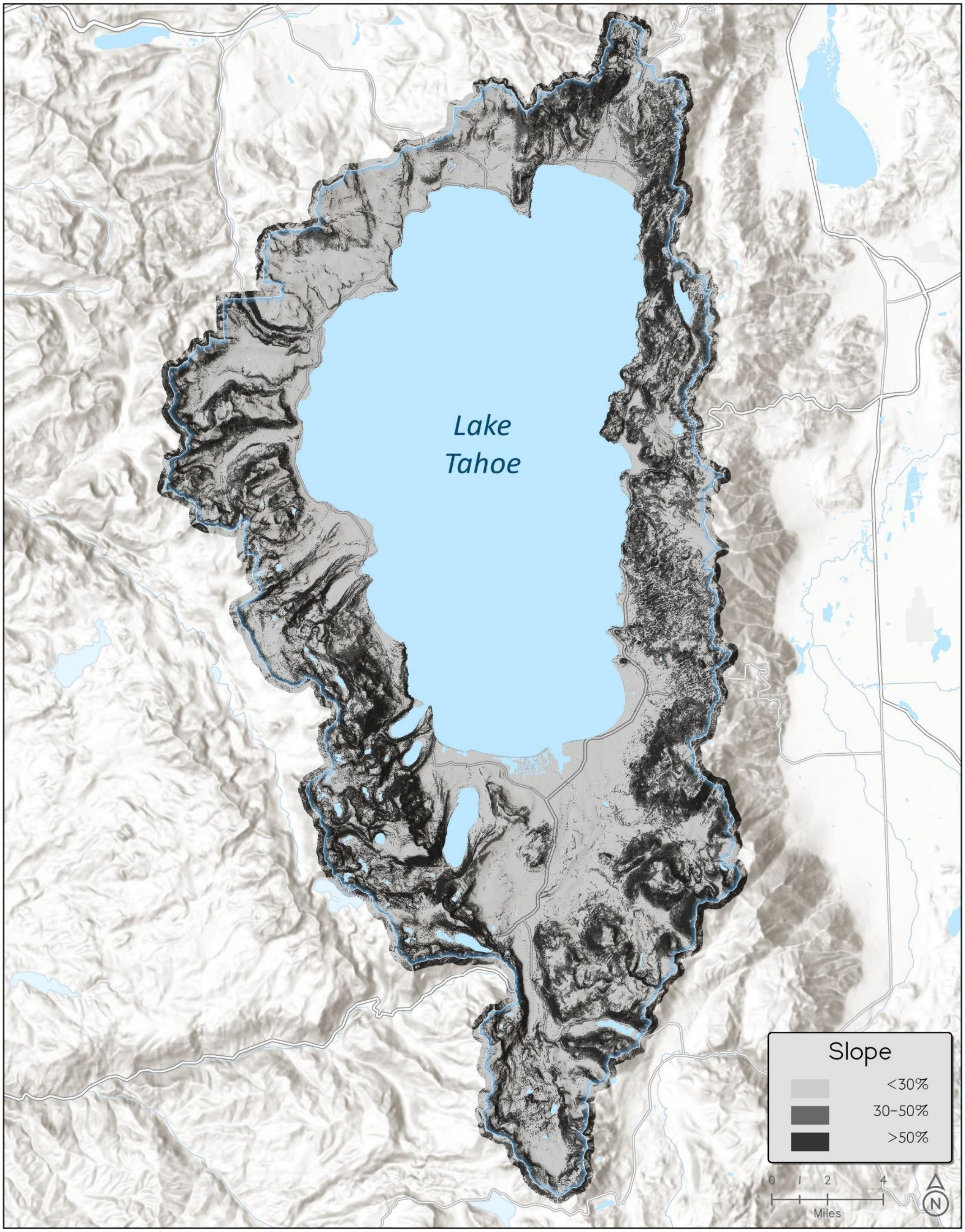


Figure 2: 30 to 50 Percent Slopes in the Lake Tahoe Basin by WUI Defense or Threat Zone

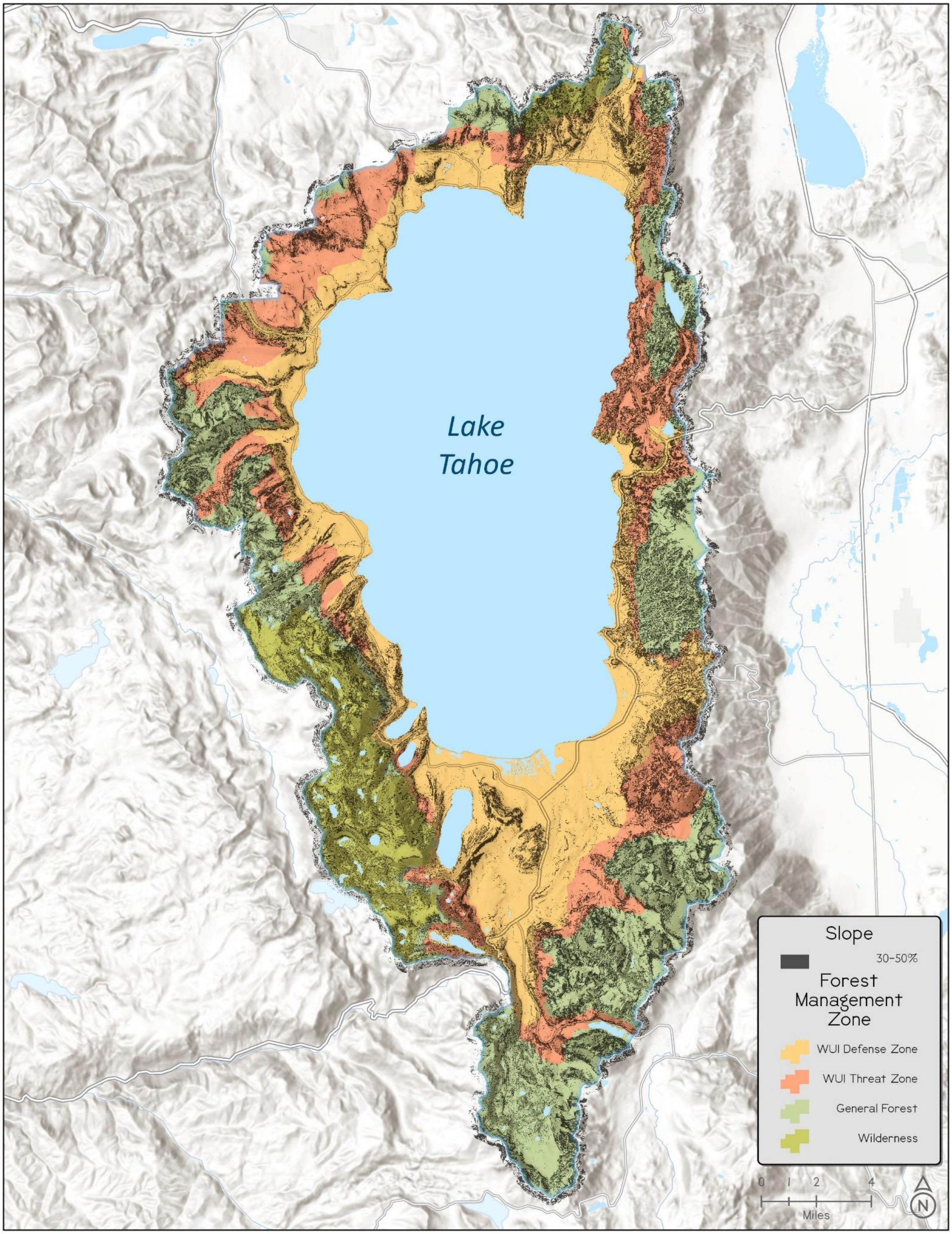
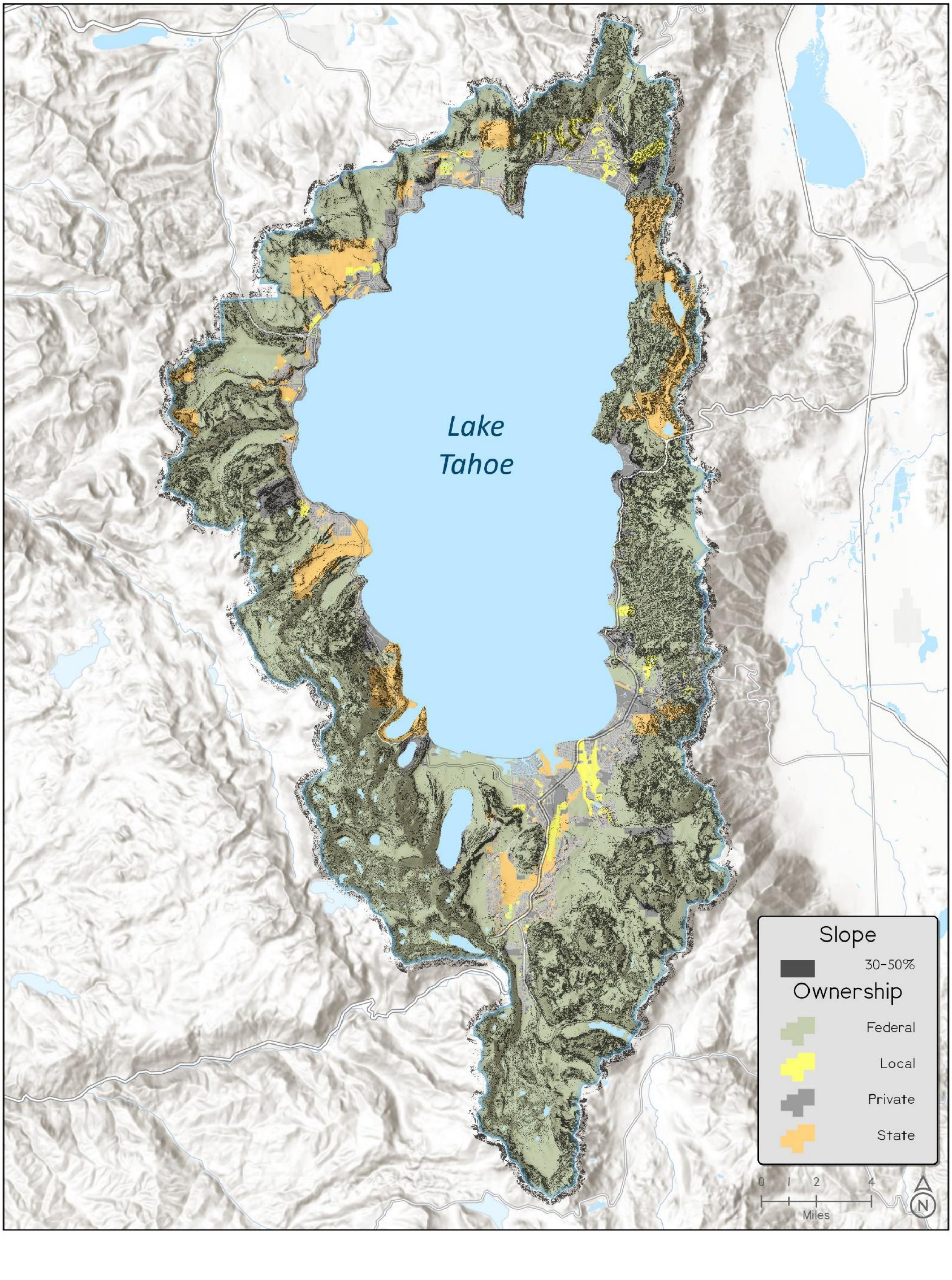


Figure 3: Land Ownership within the Tahoe Basin with 30 to 50 percent slopes



I. Environmental Impacts

1. Land

Will the proposal result in:	Yes	No	No, with mitigation	Data insufficient
a. Compaction or covering of the soil beyond the limits allowed in the land capability or Individual Parcel Evaluation System (IPES)?	☐	☒	☐	☐
b. A change in the topography or ground surface relief features of site inconsistent with the natural surrounding conditions?	☐	☒	☐	☐
c. Unstable soil conditions during or after completion of the proposal?	☐	☒	☐	☐
d. Changes in the undisturbed soil or native geologic substructures or grading in excess of 5 feet?	☐	☒	☐	☐
e. The continuation of or increase in wind or water erosion of soils, either on or off the site?	☐	☒	☐	☐
f. Changes in deposition or erosion of beach sand, or changes in siltation, deposition or erosion, including natural littoral processes, which may modify the channel of a river or stream or the bed of a lake?	☐	☒	☐	☐
g. Exposure of people or property to geologic hazards such as earthquakes, landslides, backshore erosion, avalanches, mud slides, ground failure, or similar hazards?	☐	☒	☐	☐

Discussion

The proposed code change would only allow for tree removal and forest thinning on slopes between 30 to 50 percent when proven environmentally suitable with limited erosion impacts and post-treatment remediation in place. Implementors will submit a project description, location, and initial environmental checklist for TRPA review and approval that shows all environmental protection measures to minimize slope erosion.

Additionally, implementors currently meet a variety of standards, guidelines, and requirements related to erosion and soil protection within the Tahoe Basin. For example, the Lake Tahoe Basin Management Unit 2016 Land Management Plan outlines a variety of standards and guidelines that dictate forest management practices as they related to soil compaction, erosion, and protection. These standards and guidelines include, but are not limited to:

- SG10. Avoid soil displacement to the extent practical when grading slopes, piling brush or slash, or engaging in other heavy equipment operations where earth moving is not the objective. [Guideline]
- SG11. During vegetation management activities, limit operation of wheeled or tracked vehicles and timber harvesting equipment to designated routes, and restrict operations to periods of suitable soil moisture conditions as defined in project planning documents and contracts. Suitable conditions also

include frozen ground, and/or a firm, protective base of compacted snow. When suitable conditions are not present, restrict equipment use to roads and designated stream crossings unless suitable mitigation measures can be employed. [Guideline]

- SG12. Avoid unstable areas and SEZs when reconstructing existing roads and landings or constructing new roads and landings. Minimize and mitigate impacts where avoidance is not practical. [Guideline]

Chapter 528 of Nevada Revised Statutes regarding Forest Practice and Reforestation outlines activities to minimize erosion from forestry operations. For example, NRS 528.055 states, "Skid trails, landings, logging roads and firebreaks shall be so located, constructed, used and left after timber harvesting that erosion caused by water flow therefrom and water flow in natural watercourses shall be limited to a reasonable minimum that will not impair the productivity of the soil or appreciably diminish the quality of the water." Additionally, Chapter 528 outlines best management practices and requirements as they relate to post-treatment restoration including reseeding and revegetating sites (NRS 528.057).

Article 4 of the 2021 California Forest Practice Rules outlines requirements for harvesting practices and erosion control regarding forest management in the State of California. For example, heavy equipment shall not operate on Unstable Areas. If such areas are unavoidable, the RPF shall develop specific measures to minimize the effect of operations on slope instability. These measures shall be explained and justified in the plan and must meet the requirements of 14 CCR § 914 [934, 954]. Additionally, when waterbreaks cannot sufficiently dissipate surface runoff, other erosion controls shall be installed as needed. Erosion Controls means drainage facilities, soil stabilization treatments, road and Landing Abandonment, removal and treatment of Watercourse crossings, and any other features or actions to reduce surface erosion, gullying, channel erosion, and mass erosion. Erosion controls must be repaired and maintained year-round to deal with varying weather conditions.

Due to state, federal, and TRPA requirements regarding soil erosion and minimized slope erosion, the proposed code amendments will not have significant impacts as they relate to land.

2. Air Quality

Will the proposal result in:	Yes	No	No, with mitigation	Data insufficient
a. Substantial air pollutant emissions?	☐	☒	☐	☐
b. Deterioration of ambient (existing) air quality?	☐	☒	☐	☐
c. The creation of objectionable odors?	☐	☒	☐	☐
d. Alteration of air movement, moisture or temperature, or any change in climate, either locally or regionally?	☐	☒	☐	☐
e. Increased use of diesel fuel?	☐	☒	☐	☐

Discussion

While the proposed code amendment could increase the pace and scale of restoration, most likely forest thinning and restoration activities will continue at the current pace. Additionally, implementors have a suite of best management practices they currently employ to meet air quality and noise standards associated with activities including limitations on the time trucks are allowed to idle. Likewise, implementors within the Basin currently need to meet all air quality regulations dictated by County Air Quality Control Boards or state agencies such as the Nevada Department of Environmental Protection. Lastly the proposed code amendment would have significantly less impacts to noise and air quality standards when compared to catastrophic wildfire emissions and associated emergency operations.

3. Water Quality

Will the proposal result in:	Yes	No	No, with mitigation	Data insufficient
a. Changes in currents, or the course or direction of water movements?	☐	☒	☐	☐
b. Changes in absorption rates, drainage patterns, or the rate and amount of surface water runoff so that a 20 yr. 1 hr. storm runoff (approximately 1 inch per hour) cannot be contained on the site?	☐	☒	☐	☐
c. Alterations to the course or flow of 100-yearflood waters?	☐	☒	☐	☐
d. Change in the amount of surface water in any water body?	☐	☒	☐	☐
e. Discharge into surface waters, or in any alteration of surface water quality, including but not limited to temperature, dissolved oxygen or turbidity?	☐	☒	☐	☐
f. Alteration of the direction or rate of flow of ground water?	☐	☒	☐	☐
g. Change in the quantity of groundwater, either through direct additions or withdrawals, or through interception of an aquifer by cuts or excavations?	☐	☒	☐	☐
h. Substantial reduction in the amount of water otherwise available for public water supplies?	☐	☒	☐	☐
i. Exposure of people or property to water related hazards such as flooding and/or wave action from 100-year storm occurrence or seiches?	☐	☒	☐	☐
j. The potential discharge of contaminants to the groundwater or any alteration of groundwater quality?	☐	☒	☐	☐

Discussion

The TRPA Code of Ordinances already outlines protections for water quality as it relates to forest management. For example, 61.1.5.C. requires a tree removal plan be submitted to TRPA for approval of substantial tree removal. The tree removal plan must include prescriptions for water quality protection.

The Lake Tahoe Basin Management Unit 2016 Land Management Plan lists a variety of standards and guidelines related to forest treatments and protection of water quality standards including:

- SG4. Design all Forest management activities to prevent violations of applicable water quality standards. [Guideline]
- SG5. Apply current version of the PSW Region Best Management Practices as described in Forest Service Handbook direction for Soil and Water Conservation, Water Quality Management, and Forest Service National Core BMP Technical Guide to all management activities.[Standard]
- SG7. Store fuel and other toxic materials only at designated sites. Prohibit storage of fuel and other toxic materials within SEZs except at designated administrative sites and sites covered by a Special Use Authorization. Refuel outside of SEZs unless there are no other alternatives. [Guideline]

Chapter 528 of Nevada Revised Statutes regarding Forest Practice and Reforestation (NRS 528.053) prohibits the felling of trees, skidding, rigging or construction of roads or landings, or the operation of vehicles, may take place during a logging operation within 50 feet, measured on the slope, of the high-water mark of any lake, reservoir, stream or other body of water unless a variance is first obtained pursuant to subsection 2 from a committee composed of the State Forester Firewarden, the Director of the Department of Wildlife and the State Engineer.

The California Forest Practice Rules of 2021 outline a variety of requirements associated with the protection of water quality and resources during forest management and timber harvesting including limiting the use of landings, skid trails, and roads during winter operations and ensuring all erosion and ensuring water quality BMPs are in place and functioning for all weather events or conditions. Additionally, all forestry projects within the Basin must comply with any federal and state water quality regulations including the Clean Water Act.

4. Vegetation

Will the proposal result in:	Yes	No	No, with mitigation	Data insufficient
a. Removal of native vegetation in excess of the area utilized for the actual development permitted by the land capability/IPES system?	☐	☒	☐	☐
b. Removal of riparian vegetation or other vegetation associated with critical wildlife habitat, either through direct removal or indirect lowering of the groundwater table?	☐	☒	☐	☐
c. Introduction of new vegetation that will require excessive fertilizer or water, or will provide a barrier to the normal replenishment of existing species?	☐	☒	☐	☐
d. Change in the diversity or distribution of species, or number of any species of plants (including trees, shrubs, grass, crops, micro flora and aquatic plants)?	☒	☐	☐	☐
e. Reduction of the numbers of any unique, rare or endangered species of plants?	☐	☒	☐	☐

f.	Removal of stream bank and/or backshore vegetation, including woody vegetation such as willows?	☐	☒	☐	☐
g.	Removal of any native live, dead or dying trees 30 inches or greater in diameter at breast height (dbh) within TRPA's Conservation or Recreation land use classifications?	☐	☒	☐	☐
h.	A change in the natural functioning of an old growth ecosystem?	☐	☒	☐	☐

Discussion

The proposed code amendment will allow for increased forest treatment and the use of ground-based mechanized equipment on slopes between 30 and 50 percent within the Basin. Through removal of trees, forest treatments in the Basin are typically designed to accomplish forest restoration by increasing forest resilience and decreasing the potential for high severity/catastrophic fires. Removing trees increases horizontal and vertical heterogeneity, which breaks up fuels, can promote tree growth, and provides for diverse wildlife habitat.

Implementors within the Basin currently follow a variety of best management practices associated with terrestrial invasive species control. For example, the Lake Tahoe Basin Management Unit 2016 Land Management Plan) includes several standards and guidelines related to the terrestrial invasive species including:

- SG73. Incorporate prevention and control measures into project planning, management activities and operations to prevent new introductions or contribute to spreading of invasive species, and reduce impacts from existing infestations on NFS lands, or to adjacent lands and water bodies. [Standard]
- SG74. When feasible, employ the following control measures, such as: [Guideline]
    - Use contract and permit clauses to require that the activities of contractors and permittees (including but not limited to special use permits, utility permits, pack stock operators) are conducted to prevent and control the introduction, establishment, and spread of aquatic and terrestrial invasive species.
    - Include invasive species prevention and control measures in mining plans of operation and reclamation plans.
    - When working in known invasive species infestations during project implementation, equipment and vehicles shall be cleaned before moving to other NFS lands.
    - Support partner agencies and their programs. e) Use on-site materials where feasible, unless contaminated with invasive species.
- SG75. Gravel, fill, topsoil, mulch, and other materials should be free of invasive species. [Guideline]
- SG76. New infestations are inventoried and known infestations are prioritized and contained, controlled, or eradicated using an integrated management approach. [Standard]

5. Wildlife

Will the proposal result in:	Yes	No	No, with mitigation	Data insufficient
a. Change in the diversity or distribution of species, or numbers of any species of animals (birds, land animals including reptiles, fish and shellfish, benthic organisms, insects, mammals, amphibians or microfauna)?	☐	☒	☐	☐
b. Reduction of the number of any unique, rare or endangered species of animals?	☐	☒	☐	☐
c. Introduction of new species of animals into an area, or result in a barrier to the migration or movement of animals?	☐	☒	☐	☐
d. Deterioration of existing fish or wildlife habitat quantity or quality?	☐	☒	☐	☐

Discussion

The proposed code amendment will allow for increased forest treatment and the use of ground-based mechanized equipment on slopes between 30 and 50 percent within the Basin. Through removal of trees, forest treatments in the Basin are typically designed to accomplish forest restoration by increasing forest resilience and decreasing the potential for high severity/catastrophic fires. Removing trees increases horizontal and vertical heterogeneity, which breaks up fuels, can promote tree growth, and provides for diverse wildlife habitat. Wildlife habitat will be protected, and in many cases promoted, by decreasing the potential for catastrophic wildfire and subsequently increasing forest resilience.

Implementors within the Basin must meet all state and federal threatened and endangered species laws and requirements including obtaining clearances and permits from the US Fish and Wildlife Service, the California Department of Fish and Wildlife, and the Nevada Department of Wildlife. Additionally, implementors currently manage for sensitive species such as Goshawks and Northern Spotted Owls. These habitat areas are mapped within the Basin and have a strict set of criteria for management. For example, the Lake Tahoe Basin Management Unit 2016 Land Management Plan includes standards and guidelines for the protection of species and associated habitats including, but not limited to:

- SG43. On a project specific basis, prescribe measures needed to provide for the diversity of plant and animal communities and support the persistence of native species. [Guideline]
- SG44. During project development, evaluate the project area, including any designated critical habitat, for the habitat suitability and/or occurrence of TEPCS species. [Standard]
- SG45. Implement Limited Operating Periods (LOPs) for TEPCS species and TRPA identified native species (Plan Appendix C) when determined necessary through biological review. [Standard]
- SG47. Decontaminate field clothing and gear prior to entering and when moving between cave habitats to prevent the spread of pathogens and disease. [Guideline] SG48. Maintain and restore the hydrologic connectivity of streams, meadows, wetlands, and other special aquatic features by implementing corrective actions where BMPs have not been implemented or are not effective on

roads and trails that intercept, divert, or disrupt natural surface and subsurface water flow paths. [Guideline]

- SG63. Outside of WUI defense zones, salvage harvests are prohibited in California spotted owl PACs and known carnivore den sites unless a biological evaluation determines that the areas proposed for harvest are rendered unsuitable for the purpose they were intended by a catastrophic stand-replacing event. [Standard]
- SG65. During project-specific analysis determine appropriate amount of coarse woody debris to provide for long-term habitat quality. Coarse woody debris is generally comprised of at least three downed logs per acre in varying stages of decay. [Guideline]
- SG67. Do not construct roads and trails within ¼ mile of the top or base of known cliff nesting raptor sites. [Standard]

6. Noise

Will the proposal result in:	Yes	No	No, with mitigation	Data insufficient
a. Increases in existing Community Noise Equivalency Levels (CNEL) beyond those permitted in the applicable Area Plan, Plan Area Statement, Community Plan or Master Plan?	☐	☒	☐	☐
b. Exposure of people to severe noise levels?	☐	☒	☐	☐
c. Single event noise levels greater than those set forth in the TRPA Noise Environmental Threshold?	☐	☒	☐	☐
d. The placement of residential or tourist accommodation uses in areas where the existing CNEL exceeds 60 dBA or is otherwise incompatible?	☐	☒	☐	☐
e. The placement of uses that would generate an incompatible noise level in close proximity to existing residential or tourist accommodation uses?	☐	☒	☐	☐
f. Exposure of existing structures to levels of ground vibration that could result in structural damage?	☐	☒	☐	☐

Discussion

The proposed code amendment will not increase noise disturbance or pollution above current allowances within the Tahoe Basin.

7. Light and Glare

Will the proposal:	Yes	No	No, with mitigation	Data insufficient
a. Include new or modified sources of exterior lighting?	☐	☒	☐	☐
b. Create new illumination which is more substantial than other lighting, if any, within the surrounding area?	☐	☒	☐	☐
c. Cause light from exterior sources to be cast off -site or onto public lands?	☐	☒	☐	☐
d. Create new sources of glare through the siting of the improvements or through the use of reflective materials?	☐	☒	☐	☐

Discussion

The proposed code amendment will not significantly impact light and glare.

8. Land Use

Will the proposal:	Yes	No	No, with mitigation	Data insufficient
a. Include uses which are not listed as permissible uses in the applicable Area Plan, Plan Area Statement, adopted Community Plan, or Master Plan?	☐	☒	☐	☐
b. Expand or intensify an existing non-conforming use?	☐	☒	☐	☐

Discussion

The proposed code amendment will not significantly impact land use.

9. Natural Resources

Will the proposal result in:	Yes	No	No, with mitigation	Data insufficient
a. A substantial increase in the rate of use of any natural resources?	☐	☒	☐	☐
b. Substantial depletion of any non-renewable natural resource?	☐	☒	☐	☐

Discussion

While this code amendment would promote the removal of trees through ground-based mechanical equipment and may have implications for an increased pace and scale of treatment within the Basin, the benefits of decreased high severity fire risk and increased forest resilience outweigh the potential removal of trees. Likewise, any impacts from the depletion of trees or use of trees by this action would be offset by the potential savings of more trees from high severity wildfire or a mass mortality event from insects and disease spreading through even-aged and dense tree stands.

10. Risk of Upset

Will the proposal:	Yes	No	No, with mitigation	Data insufficient
a. Involve a risk of an explosion or the release of hazardous substances including, but not limited to, oil, pesticides, chemicals, or radiation in the event of an accident or upset conditions?	☐	☒	☐	☐
b. Involve possible interference with an emergency evacuation plan?	☐	☒	☐	☐

Discussion

The proposed code amendment would not have significant impacts regarding risk of upset.

11. Population

Will the proposal:	Yes	No	No, with mitigation	Data insufficient
a. Alter the location, distribution, density, or growth rate of the human population planned for the Region?	☐	☒	☐	☐
b. Include or result in the temporary or permanent displacement of residents?	☐	☒	☐	☐

Discussion

The proposed code amendments would not have a significant impact on population.

12. Housing

Will the proposal:	Yes	No	No, with mitigation	Data insufficient
a. Affect existing housing, or create a demand for additional housing? To determine if the proposal will affect existing housing or create a demand for additional housing, please answer the following questions:				
1. Will the proposal decrease the amount of housing in the Tahoe Region?	☐	☒	☐	☐
2. Will the proposal decrease the amount of housing in the Tahoe Region historically or currently being rented at rates affordable by lower and very-low-income households?	☐	☒	☐	☐
b. Will the proposal result in the loss of housing for lower-income and very-low-income households?	☐	☒	☐	☐

Discussion

The proposed code amendments would not have a significant impact on housing.

13. Transportation / Circulation

Will the proposal result in:	Yes	No	No, with mitigation	Data insufficient
a. Generation of 100 or more new Daily Vehicle Trip Ends (DVTE)?	☐	☒	☐	☐
b. Changes to existing parking facilities, or demand for new parking?	☐	☒	☐	☐
c. Substantial impact upon existing transportation systems, including highway, transit, bicycle or pedestrian facilities?	☐	☒	☐	☐
d. Alterations to present patterns of circulation or movement of people and/or goods?	☐	☒	☐	☐
e. Alterations to waterborne, rail or air traffic?	☐	☒	☐	☐
f. Increase in traffic hazards to motor vehicles, bicyclists, or pedestrians?	☐	☒	☐	☐

Discussion

The proposed code amendments would not have a significant impact on transportation.

14. Public Services

Will the proposal have an unplanned effect upon, or result in a need for new or altered governmental services in any of the following areas?:	Yes	No	No, with mitigation	Data insufficient
a. Fire protection?	☐	☒	☐	☐
b. Police protection?	☐	☒	☐	☐
c. Schools?	☐	☒	☐	☐
d. Parks or other recreational facilities?	☐	☒	☐	☐
e. Maintenance of public facilities, including roads?	☐	☒	☐	☐
f. Other governmental services?	☐	☒	☐	☐

Discussion

The proposed code amendments would not have a significant impact on public services.

15. Energy

Will the proposal result in:	Yes	No	No, with mitigation	Data insufficient
a. Use of substantial amounts of fuel or energy?	☐	☒	☐	☐
b. Substantial increase in demand upon existing sources of energy, or require the development of new sources of energy?	☐	☒	☐	☐

Discussion

Ground-based mechanical equipment for tree removal uses diesel fuel. It is not anticipated that the amount of diesel fuel used will be substantially larger than what is currently used within the Basin for tree removal projects. For this reason, the proposed code amendments will not have a significant impact on energy.

16. Utilities

Except for planned improvements, will the proposal result in a need for new systems, or substantial alterations to the following utilities:	Yes	No	No, with mitigation	Data insufficient
a. Power or natural gas?	☐	☒	☐	☐
b. Communication systems?	☐	☒	☐	☐
c. Utilize additional water which amount will exceed the maximum permitted capacity of the service provider?	☐	☒	☐	☐
d. Utilize additional sewage treatment capacity which amount will exceed the maximum permitted capacity of the sewage treatment provider?	☐	☒	☐	☐
e. Storm water drainage?	☐	☒	☐	☐
f. Solid waste and disposal?	☐	☒	☐	☐

Discussion

The proposed code amendments will not have a significant impact on utilities.

17. Human Health

Will the proposal result in:	Yes	No	No, with mitigation	Data insufficient
a. Creation of any health hazard or potential health hazard (excluding mental health)?	☐	☒	☐	☐
b. Exposure of people to potential health hazards?	☐	☒	☐	☐

Discussion

The proposed code amendments will not have a significant impact on human health.

18. Scenic Resources / Community Design

Will the proposal:	Yes	No	No, with mitigation	Data insufficient
a. Be visible from any state or federal highway, Pioneer Trail or from Lake Tahoe?	☒	☐	☐	☐
b. Be visible from any public recreation area or TRPA designated bicycle trail?	☒	☐	☐	☐
c. Block or modify an existing view of Lake Tahoe or other scenic vista seen from a public road or other public area?	☐	☒	☐	☐
d. Be inconsistent with the height and design standards required by the applicable ordinance or Community Plan?	☐	☒	☐	☐
e. Be inconsistent with the TRPA Scenic Quality Improvement Program (SQIP) or Design Review Guidelines?	☐	☒	☐	☐

Discussion

The proposed code amendment will not have long-term impacts on scenic resources or community design. While there may be short-term localized impacts from treatment units, these impacts will be temporary and significantly less than the potential scenic impacts of a catastrophic wildfire or large insect and disease event. While impacts may be visible from roads or trails, the projects will improve visual quality by returning landscapes to more natural and historical stand densities, reducing fire risk, and increasing forest resilience. Additionally, implementors within the Basin must currently meet all TRPA scenic requirements as outlined in Chapter 66 of the TRPA Code of Ordinances.

Lastly, implementors currently take into consideration scenic impacts related to forest management. For example, the Lake Tahoe Basin Management Unit 2016 Land Management Plan lists the follow standards and guidelines related to scenic resources:

- SG117. Scenic resource and built environment guidelines are incorporated into management activities and into the design and development of agency facilities.
- SG116. All resource management and permitted activities shall meet or exceed the established scenery objectives shown on the Minimum Scenic Integrity Objective (MSIO) map. Utilize techniques such as: [Standard]
    - Size areas cleared for management objectives to meet minimum requirements for operability and safety.
    - With consideration for scenic objectives, maintain clumps of trees within cleared areas if they do not pose a safety or operational risk.
    - Maintain understory vegetation within cleared corridors if they do not pose a safety or operational risk

19. Recreation

Will the proposal:	Yes	No	No, with mitigation	Data insufficient
a. Create additional demand for recreation facilities?	☐	☒	☐	☐
b. Create additional recreation capacity?	☐	☒	☐	☐
c. Have the potential to create conflicts between recreation uses, either existing or proposed?	☐	☒	☐	☐
d. Result in a decrease or loss of public access to any lake, waterway, or public lands?	☐	☒	☐	☐

Discussion

There may be short-term, localized impacts from temporary closures to public lands and recreation areas in the event a treatment unit overlaps a recreation site; however, these impacts will be temporary and significantly less than potential long-term impacts associated with a catastrophic wildfire that could include permanent closure and complete loss of a recreation site and resources.

20. Archaeological / Historical

	Yes	No	No, with mitigation	Data insufficient
a. Will the proposal result in an alteration of or adverse physical or aesthetic effect to a significant archaeological or historical site, structure, object or building?	☐	☒	☐	☐
b. Is the proposed project located on a property with any known cultural, historical, and/or archaeological resources, including resources on TRPA or other regulatory official maps or records?	☐	☒	☐	☐
c. Is the property associated with any historically significant events and/or sites or persons?	☐	☒	☐	☐
d. Does the proposal have the potential to cause a physical change which would affect unique ethnic cultural values?	☐	☒	☐	☐
e. Will the proposal restrict historic or pre-historic religious or sacred uses within the potential impact area?	☐	☒	☐	☐

Discussion

Implementors must comply with all State Historic Preservation Office regulations as outlined by the States of Nevada and California. These requirements typically include surveying for known or unknown archaeological and historical resources prior to implementation and flagging and avoiding of resources when possible. Additionally, implementors regularly consult and coordinate with the Washoe Tribe regarding culturally sensitive and important resources within the Basin and any potential restoration or management impacts.

21. Findings of Significance

	Yes	No	No, with mitigation	Data insufficient
a. Does the project have the potential to degrade the quality of the environment, substantially reduce the habitat of a fish population to drop below self-sustaining levels, threaten to eliminate a plant or animal community, reduce the number or restrict the range of a rare or endangered plant or animal or eliminate important examples of the major periods of California or Nevada history or prehistory?	☐	☒	☐	☐
b. Does the project have the potential to achieve short-term, to the disadvantage of long-term, environmental goals? (A short-term impact on the environment is one which occurs in a relatively brief, definitive period of time, while long-term impacts will endure well into the future.)	☐	☒	☐	☐
c. Does the project have impacts which are individually limited, but cumulatively considerable? (A project may impact on two or more separate resources where the impact on each resource is relatively small, but where the effect of the total of those impacts on the environmental is significant?)	☐	☒	☐	☐
d. Does the project have environmental impacts which will cause substantial adverse effects on human being, either directly or indirectly?	☐	☒	☐	☐

Discussion

The proposed code amendments will not have significant impacts.

Determination:

On the basis of this evaluation:

a. The proposed project could not have a significant effect on the environment and a finding of no significant effect shall be prepared in accordance with TRPA's Rules of Procedure	☒ YES	☐ NO
b. The proposed project could have a significant effect on the environment, but due to the listed mitigation measures which have been added to the project, could have no significant effect on the environment and a mitigated finding of no significant effect shall be prepared in accordance with TRPA's Rules and Procedures.	☐ YES	☒ NO
c. The proposed project may have a significant effect on the environment and an environmental impact statement shall be prepared in accordance with this chapter and TRPA's Rules of Procedures.	☐ YES	☒ NO

Signature of Evaluator

Date 2/14/2022

Forest Health Program Manager
Title of Evaluator

Attachment D

Dobre et al. 2021. “Assessing the Effects of Forest Treatments and Wildfires on Sediment Yield in the Lake Tahoe Basin.” Draft WEPP Analysis Report.

Assessing the Effects of Forest Treatments and Wildfires on sediment yield in the Lake Tahoe Basin

prepared by

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Contents

I. SUMMARY

Past forest fuel management activities in the Lake Tahoe Basin have focused on the wildland/urban interface (WUI) to reduce the risk of wildfire to homes and other structures. However, given the increase in wildfire activity within the recent years, land managers within the basin are considering increasing forest treatments to more remote forested areas and on steeper slopes (30−50%), activities that have the potential to also increase soil erosion. This is a great concern in the basin since Lake Tahoe is renowned for its clear waters and eroded sediment can decrease water quality.

To address some of the managers' concerns related to increase soil erosion from forest treatments, we conducted a modeling study to simulate surface runoff and soil erosion from various management conditions followed by a series of data analyses based on the model hillslope results. We first applied the Water Erosion Prediction Project (WEPP) to all watersheds within the Lake Tahoe Basin for eleven management conditions, including current conditions, thinning, prescribed fire, and wildfire, and then performed a series of data summaries and statistical analyses to better understand the relationship between hillslope sediment yield and various environmental variables. While the main focus of the study was to specifically evaluate forest treatments on steep slopes, the large amount of data generated through this modeling exercise allowed us to expand our analyses to other environmental variables to better understand variability in sediment yield due to factors other than slope steepness.

The WEPP model was calibrated to match daily and annual values of surface runoff, sediment yield, and phosphorus, at the outlets of 17 watersheds within the basin. Overall, only minimal calibration was necessary to achieve satisfactory model performance. The model captured runoff regimes across all watersheds reasonably well, and the simulated annual trends of water yield followed the trends of observed yield. The basin-scale data summaries and statistical analyses, revealed that mechanical thinning on steeper slopes can increase soil erosion through rutting, however, current management are likely to use newer harvesting methods and equipment to minimize soil disturbance and increase ground cover. Additionally, the increases in sediment yield with thinning are not statistically significant and they need to be evaluated in terms of other ecological benefits, such as maintaining healthy ecosystems and avoiding the costs of catastrophic high severity fires.

From our analyses other variables emerged as having an influence on soil erosion, such as slope length, slope area, slope width, and precipitation. Specifically slope length appeared as an important variable in all statistical analyses, therefore managers should consider thinning activities that either include buffers or add natural breaks along the slopes (i.e. thin only portions of a slope). Since the conclusions in this study are based on modeling results and not on soil erosion from field data, these results should

be used in combination with other tools and knowledge to make informed future management decisions in the Lake Tahoe Basin.

II. INTRODUCTION

Wildfire activity has been increasing since the mid-1980s in the western U.S. (Westerling et al., 2006) and multiple recent studies suggest that it will continue to increase in the next decades (Yue et al., 2014, Williams et al., 2019, Higuera and Abatzoglou 2021). Within the state of California there was a fivefold increase in annual burned area between 1972−2018 (Williams et al., 2019), with year 2020 experiencing five of the six largest wildfires in state history (Higuera and Abatzoglou 2021). The increase in wildfire activity is mainly attributed to anthropogenic climate changes, specifically to shifts in land use and land use practices, among others (Abatzoglou et al., 2020, Bowman et al., 2020, Coop et al., 2020). In the largely forested areas of the Sierra Nevada mountains, the burned areas are projected to increase by 50% by midcentury. Similarly, Williams et al. (2019) projected an eightfold increase in annual summer forest-fire extent in forested North Coast and Sierra Nevada regions. These statistics are concerning for land and water managers responsible for protecting natural resources.

Forest treatments, especially mechanical thinning and prescribed fires have been proposed as effective measures to reduce wildfire risks (Schwilk et al., 2009, Agee and Skinner, 2005) but also to improve forest resistance to drought and to restore forest structure to historic conditions (Low, 2021). Despite these recommendations, some forest treatments, such as prescribed fires, are still not widely implemented, which is attributed to various factors including favorable weather for burning, air quality constrains, and negative social perception (Kolden 2019).

Fuel reduction treatments using mechanical equipment have commonly been limited to slopes less than 40% on national forest lands in the Sierra Nevada (North et al., 2015). In the Lake Tahoe Basin, regulatory agencies had limited treatments on slopes greater than 30% based on the Bailey Land Capability System developed in the 1970s (Long, 2009), limitations that are mainly driven by water quality and clarity standards (Safford et al., 2009). However, agencies in the Lake Tahoe Basin and other parts of the Sierra Nevada are now interested in the potential benefits and risks of conducting fuel reduction and forest restoration treatments, specifically ground-based thinning using heavy equipment, on slopes greater than 30% to reduce the potential risk of wildfires.

More recently, land managers and scientists have been warned that treatments on steep slopes are important to reduce the potential impacts of severe wildfires (Long, 2009). For example, following the Angora Fire (2007), Safford et al., 2009 examined the effects of previous fuel treatments on fire severity and reported that an area of steeper slopes had been treated only with hand-thinning and consequently experienced more severe fire; the study also noted that forest thinning on steep slopes needs to be more extensive to achieve a similar fire hazard reduction as on gentle slopes.

Some research has cautioned that slope steepness is a risk factor for soil erosion, but many studies have not found it to be a significant driver of erosion rates. For example, one study (Fox and Bryan, 2000) noted a general slope-erosion relationship, finding that "for a constant runoff rate, soil loss increased roughly with the square root of slope gradient." However, another study found that steep slopes develop geomorphic features that moderate erosional energy (Giménez and Govers, 2001). A study in New Mexico (Cram et al., 2007) found that steep slopes (26% to 43%) in a mixed-conifer forest in central New Mexico were potentially susceptible to rutting from tires on equipment, and they noted that exposed bare soil was a key indicator. When litter was disturbed but not displaced (characterized as only light to moderate disturbance), runoff and sedimentation on steep slopes did not exceed non-disturbed sites. The authors concluded that advanced equipment such as forwarding beds can avoid erosion from surface disturbance.

The general concern that steep slopes are vulnerable to erosion is often linked to practices sometimes associated with mechanical harvest including clearing and road or trail construction that reduce root strength and increase water runoff (Sidle et al., 2006). Such pronounced effects are unlikely to result from fuel reduction thinning that adheres to best management practices (BMPs), such as limiting the extent and connectivity of disturbed areas (e.g. designated location for landing and spacing of skid trails and burn piles).

Forest treatments, slope steepness, and soil erosion in the basin

Land managers in the Lake Tahoe Basin are focused on harvest using ground-based machines, although cable-yarding and loaders have been considered as alternative harvest technologies for steep slopes (Han and Han, 2020); such treatments pose different risks in terms of erosion, with little risk where logs can be fully suspended.

A field study of erosion risk from thinning and prescribed burning was conducted in the Lake Tahoe Basin (Harrison et al., 2016); that study included four sites with slopes exceeding 30% (Table 1):

Table 1: Sites with slope over 30% in a field study of erosion in the Lake Tahoe Basin.

Site	Avg. slope (%)	Soil type	Parent material	Hydraulic conductivity ($cm\ s^{-1}$)	Bulk density (field) ($g\ cm^{-3}$)
Incline 1	38	JO-TA	Volcanic	0.001	0.89
Incline 2	38	JO-TA	Volcanic	0.001	1.16
Slaughterhouse 1	35	CS-CG	Granitic	0.001	1.11
Slaughterhouse 2	34	CS-CG	Granitic	0.006	1.23

JO-TA = Jorge-Tahoma; CS-CG = Cassenai-Cagwin

In their results for mastication and prescribed burning, slope was not a significant predictor of erosion. No sediment yield was observed for plots with up to 60% of the surface area burned, despite steep slopes. The authors observed that several practices commonly used in the basin likely limited erosion effects, including dry season operations, limited passes with equipment, application of slash in trails, and use of low ground-pressure vehicles, as has been reported from other areas (Zamora-Cristales et al., 2014). They also noted that steeper slopes were unlikely to be treated with mastication and less likely to be treated with prescribed fire due to implementation challenges. However, they noted that their results "should not be extrapolated to steeper sites".

A recent follow-up to a pile burning study in the basin noted that pile burning generally did not pose erosion hazards. However, the researchers found that one site, which had not reestablished vegetative cover after several years, was located on a steep slope (Busse et al., 2018). Despite that issue, the authors noted that the eroded sediments did not move far down slope.

A review of fuel treatment effects on soils (Verburg et al., 2009) mentioned some earlier field studies in the basin and cited a rainfall simulation experiment on granitic soils (Cagwin series). The study found that interrill erosion increased significantly as slope class increased from 15−30% to greater than 30%, but slope had no significant effect on infiltration and runoff (Guerrant et al., 1991). They also noted that soil type appeared to have relative low erosion risk. A follow-up study (Naslas et al., 1994) conducted on three slope classes (<15%, 15−30%, >30%), found that erodibility was more dependent on soil type, plot condition and duration of a rainfall event rather than steepness. Those studies suggested that more simplistic classification systems, like the Bailey system, were insufficient to evaluate erosion potential.

Studies from Wildfire Settings

Several studies in wildfire contexts have not found slope to be a main contributor to erosion, especially where the slope exceeds 10−20%. In a study in Colorado, Benavides-Solorio and MacDonald (2005) measured the rates of sediment yield at 48 hillslope-scale plots from three prescribed fires and three wildfires. The authors then quantified the effects of various environmental variables (including slope) on sediment yield and developed empirical models to predict post-fire sediment. Approximately 77% of the model variability in sediment production rates was explained by percent bare soil, rainfall erosivity, fire severity, soil water repellency, and soil texture. Surprisingly, slope was not selected by any of the predicted models, which the authors attributed to the lower variability in slopes (25−45%).

Similar results were found in a separate study, also in Colorado, where slope had limiting effects on sediment yield (Pietraszek, 2006). The authors also attributed these results to the lower variability in slope steepness (20−40%).

Slope steepness was also not important in a study in Montana where the authors found that 75% of the variance in first-year post-fire hillslope erosion rates was explained by the 10-minute rainfall intensity (I_{10}). Other site characteristics, such as ground cover, water repellent soil conditions, and slope steepness were obscured when I_{10} was greater than 70 mm/h (Spigel and Robichaud, 2007).

Effects of ground cover on soil erosion

The most critical influence of management on soil erosion is through its effect vegetative residue (live plants, wood, or litter) covering the soil. Rock fragments can also provide soil protection from raindrop splash, aggregate disintegration, and detachment by overland flow. The role of ground cover on limiting soil erosion applies throughout forested landscapes. Consequently, when using any model to project erosion in forested landscapes, the effects of natural disturbances like wildfire as well as management activities such as thinning, prescribed fire, trails and roads on ground cover are critical.

Forest fuel reduction efforts attempt to reduce surface fuels while maintaining sufficient ground cover to inhibit erosion. In practices observed in the Lake Tahoe Basin, residual ground covers are likely to be effective. Research by Harrison et al. (2016) confirmed that even relatively low (25%) levels of ground cover, in the form of masticated fuels or duff, could effectively inhibit erosion, and that maintaining patchy ground cover could be more beneficial than maintaining continuous ground cover.

Concerns with parameters other than ground cover

Studies of soil quality and forest treatment effects have often examined soil compaction, and that indicator has been a focus of soil monitoring in the basin (Norman et al., 2008). Compaction by heavy equipment can have negative impacts on vegetation, particularly seedlings (Mariotti et al., 2020). However, such concerns may be less significant for fuel reduction contexts in the Lake Tahoe Basin, where treatments commonly occur on coarsely-textured granitic soils and are expected to reduce small trees. While compaction is important for hydrology (change in infiltration leads to increased overland flow and potential for erosion), the amount of cover is a more direct control on erosion rates (Prats et al., 2019). One concern is that wheeled or tracked vehicles might be more subject to slippage on steep slopes, which could lead to gouging of soils, but experienced operators and oversight may limit or mitigate such potential.

III. <u>METHODS</u>

The WEPP model

The Water Erosion Prediction Project (WEPP) model is a physically-based, continuous-simulation, distributed-parameter model (Flanagan and Nearing, 1995). The WEPP technology is based on the fundamentals of hydrologic and erosion science (Nearing et al., 1990) and has been initially developed and successfully applied to predict soil erosion from small agricultural catchments (Flanagan and Nearing, 1995, Flanagan et. al., 2007). However, in the recent years the model has been improved to predict sediment delivery from larger forested watersheds. Major recent improvements include the incorporation of the Muskingum-Cunge channel routing algorithms (Wang et al, 2014) and of a simple linear reservoir algorithm (Srivastava et al., 2013, Srivastava et al., 2017, and Srivastava et al., 2018, Brooks et al., 2016), which now allows users to apply the model to larger watersheds characterized by baseflow.

The WEPPCloud online GIS interface

WEPPcloud (https://wepp.cloud) is an online interface for the WEPP model that allows users to run hydrologic simulations and view model results without downloading any data or software on their computers. To run predictions of runoff and erosion, users only need a computer connected to the internet. All input, output, and model runs are stored online and can be accessed by the user at a later time or shared with other collaborators. The Lake Tahoe interface (https://wepp.cloud/weppcloud/lt/) is site-specific and all input data, especially the management files, were specifically created for this project based on data from literature and from previous field measurements.

Study sites and watershed delineation

For this study, we selected all watersheds around the Lake Tahoe Basin (Fig. 1), with a few exceptions. We excluded ski runs because treatments at such sites are likely to differ from the general forest and would require more customization. Similarly, urban areas and small “frontal” watersheds that are concentrated in the Wildland-Urban Interface (WUI) were not specifically modeled because WEPP was designed as a wildland model. Urban areas with impervious surfaces require more complex calibration and customization of input parameters. The Lower Truckee watershed in the NW side of the lake flows out of the basin. Therefore, this area was excluded from the analyses.

The watersheds were delineated based on a USGS National Elevation Dataset (NED) at 30-m resolution using the TOPAZ (Garbrecht and Martz, 1999) model. Two parameters are needed to delineate watersheds: a Critical Source Area (CSA—the threshold area at which the channel begins) and a Minimum Source Channel Length (MSCL—the minimum length of a channel). Higher MSCL and CSA values will delineate watersheds with less number of hillslopes but longer lengths, while smaller values will delineate more number of hillslopes but shorter lengths. In the current simulations we used MSCL = 60 and CSA = 5.

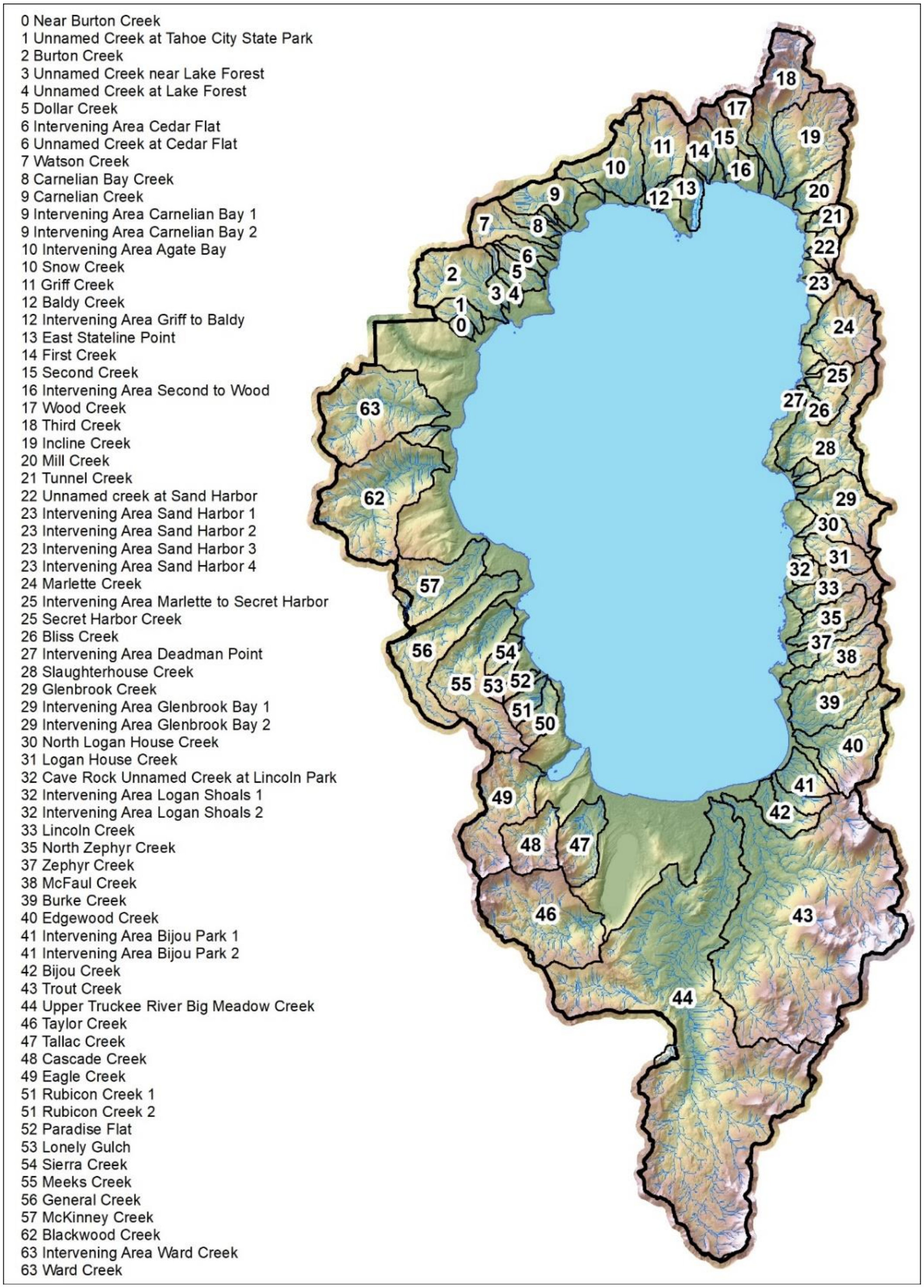

Fig. 1. Watershed boundaries and names of the simulated watersheds.

Model setup and input data

Soils and Landcover/Managements

The soil and management files are created based on default values in WEPP or are extracted from national databases. The WEPP soil input files require: *rill* and *interrill erodibility*, *critical shear*, *effective hydraulic conductivity*, *soil depth*, *%sand*, *%silt*, *%clay*, *%rock*, *%organic matter*, *CEC*, *bulk density*, *hydraulic conductivity*, *wilting point*, and *field capacity* for each soil layer. We automatically extracted all these parameters from the NRCS SSURGO database and created a soil file for each hillslope in each watershed. Similarly, we identified a landcover type based on the 2016 NCDL Landcover map (e.g. deciduous forest, evergreen forest, shrubland, etc.) and then created a Tahoe-specific WEPP management file similar to Brooks et al., 2016, and assigned it to each hillslope. Although WEPP requires several vegetative parameters, the most sensitive ones are %canopy cover, %rill and %interrill ground covers, and Leaf Area Index (LAI). These input files were the basis for the "Current Conditions" scenario.

Weather data

In the Lake Tahoe model runs we used the historic gridded Daymet at 1 km spatial resolution (Thornton et al. 2016) database to acquire daily precipitation, maximum and minimum temperature at each hillslope within the modeled watersheds between 1990–2019. The rest of the weather parameters (storm duration, time to peak intensity, peak intensity, solar radiation, average wind speed and duration, and dew point temperature) were stochastically generated based on the nearby Tahoe, CA station, using the CLIGEN weather generator (Nicks and Lane 1989, Srivastava et al. 2019).

For the future climate scenario, we used the A2 climate scenario (Coats et al., 2013) for the daily precipitation, maximum and minimum temperature and CLIGEN for the remaining parameters. An important observation is that the CLIGEN model uses current weather stations to generate local storm durations and intensities and, therefore, might not be comparable to future storm characteristics. Future model simulations are between 2018–2048. The weather files were built to match the streamflow and water quality data available at the outlet of the modeled watersheds (Table 2).

Model calibration and performance assessment

Model accuracy assessment was performed on 17 watersheds in the basin with long-term observed USGS data (Fig. 2; Table 2). To calibrate the model, we ran the WEPPcloud interface with default parameters and downloaded all the model runs (including all the input and output data) with the wepppy-win-bootstrap, a freely available Python package developed to allow advanced users to download, modify, and run WEPPcloud projects locally on Windows computers (Lew, 2021). We first calibrated daily streamflow and total water yield as described below and then calibrated key parameters related to sediment and phosphorus yield. Model performance was assessed for each watershed simulation by utilizing a variety of publicly available USGS data sources: daily streamflow data measured at USGS gauging stations, flow-weighted annual loads of sediment and phosphorus processed in previous studies, and flow-weighted monthly concentrations of phosphorus. Model performance efficiency was assessed using several goodness-of-fit statistics: the Nash-Sutcliffe

Efficiency (*NSE*; Nash and Sutcliffe, 1970), the Kling-Gupta efficiency (*KGE*; Gupta et al., 2009), and percent bias (*PBias* (%); Yapo et al., 1996). These indices were calculated with the '*hydroGOF'* R package (Zambrano-Bigiarini, 2020).

Table 2. List of gauged study watersheds, simulation dates, areas, elevations, and precipitation. Full USGS station codes and names, the corresponding WEPPcloud interface model run names, and web addresses for the model runs are provided in the supplementary material (Table A1 in Appendix).

No.	Name	USGS station	Simulation date range YYYY/MM/DD		Watershed area	Min. elevation	Max. elevation	Mean Annual Precipitation
			Start	End	(ha)	(m)	(m)	(mm)
				California				
1	WC8[§]	10336676	1990/01/01	2014/09/30	2310	1920	2700	1406
2	WC7A[§]	10336675	1991/10/01	2001/09/30	2170	1967	2700	1414
3	WC3A[§]	10336674	1991/10/01	2011/11/01	1160	2021	2700	1496
4	BC1	10336660	1990/01/01	2014/09/30	2670	1904	2676	1476
5	GC1	10336645	1990/01/01	2014/09/30	1820	1913	2640	1271
6	UTR1[§]	10336610	1990/01/01	2014/09/30	13320	1899	3052	1025
7	UTR3[§]	103366092	1990/06/01	2012/09/30	9380	1926	3050	1117
8	UTR5[§]	10336580	1990/05/12	2011/10/11	3410	1981	3050	1218
9	TC4[§]	10336780	1990/01/01	2014/09/30	9870	1899	3306	905
10	TC2[§]	10336775	1990/06/01	2012/09/30	5560	1914	3259	880
11	TC3[§]	10336770	1990/05/22	2011/03/31	1780	2124	3259	900
				Nevada				
12	LH1	10336740	1990/01/01	2011/10/12	500	2030	2688	657
13	GL1	10336730	1990/01/01	2012/09/30	990	1903	2689	616
14	IN1[§]	10336700	1990/01/01	2014/09/30	1580	1904	2807	928
15	IN2[§]	103366995	1990/01/01	2004/09/30	1070	1942	2807	999
16	IN3[§]	103366993	1990/05/01	2011/03/31	690	2114	2807	1061
17	TH1	10336698	1990/01/01	2014/09/30	1470	1900	3135	1081

[§] *Denotes nested watersheds.*

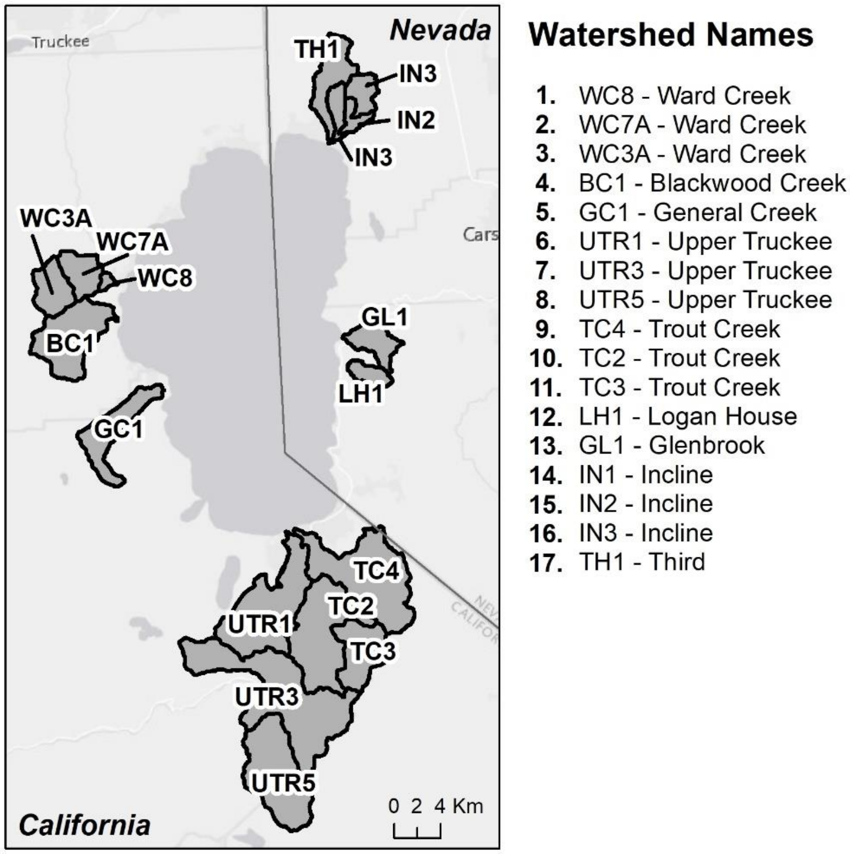

Fig. 2. Watersheds with observed data used for calibration.

Streamflow and water yield

Streamflow calibration was performed using only the linear baseflow recession coefficient (k_b). The k_b coefficient represents the fixed proportion of the total water stored in a dynamic groundwater reservoir that provides baseflow to the stream on any given day and typically varies between 0.01 d^{-1} and 0.1 d^{-1} (Beck et al., 2013; Sánchez-Murillo et al., 2014). Brooks et al. (2016) determined that the observed streamflow recessions on the western side of Lake Tahoe could be represented by a linear reservoir coefficient k_b of 0.04 d^{-1}. However, due to a complex hydrogeology of the east side of the Lake Tahoe Basin, attributed to large geologic faults and high permeability rates (Nolan and Hill, 1991), the authors proposed that additional deep seepage losses of groundwater were occurring and suggested that the rate of groundwater loss from the reservoir could be quantified by calibrating a second deep seepage reservoir coefficient (k_s) for groundwater lost from the system. For our simulations, we assigned a default k_b value of 0.04 d^{-1} to all modeled watersheds from the west-side of the basin and calibrated the k_b and k_s coefficients for the east-side watersheds similar to the Brooks et al. (2016) approach. For the streamflow model performance assessment, we used a maximum of 25 years (1990–2014) of observed daily streamflow data at the 17 watersheds identified in Table 2.

Sediment yield

The WEPP model can simulate soil erosion from hillslopes and channels, soil deposition within the hillslope and channel profile, and sediment yield at the watershed outlet. The most important calibrating parameters for simulating soil erosion are effective hydraulic conductivity, rill and interrill erodibilities, hillslope critical shear, percent ground cover, and channel bed critical shear stress (τ_c) (Nearing et al., 1990). For hillslopes, these parameters were set by default in the WEPPcloud interface based on previous field observations in forest soils of various textures (Lew et al., 2021). Similarly, for channel erosion, Srivastava et al. (2020) demonstrated good agreement between observed and model simulations in the seven watersheds in the Mica Creek Experimental Watershed in North Idaho (MCEW) by varying only the channel τ_c. The authors found a direct relationship between WEPP-calibrated τ_c and the median particle size (D_{50}) and suggested that pebble count data can be used to parametrize the channel τ_c in forested watersheds. In the Lake Tahoe watersheds, pebble count data were available at few locations, which were provided by the land managers. We calculated the D_{50} from the observed pebble count data and identified the channel bed critical shear stress-equivalent following Berenbrock and Tranmer (2008).

Observations of event-based suspended sediment concentrations (SSC) were available at the USGS gauging stations for all modeled watersheds in the Lake Tahoe Basin. Additionally, we also had available flow-weighted annual loads of SSC estimated in a previous study in the basin by Coats et al. (2016). The authors estimated and compared annual loads from several regression equations after correcting the sources of bias in the USGS water quality database.

Phosphorus yield

Simulated phosphorus yield in WEPPcloud is based on simple static phosphorus concentrations in each of the three components of the streamflow hydrograph (surface runoff, subsurface lateral flow, and baseflow), and particulate phosphorus concentration on the delivered sediment. These static concentrations were calculated based on long term observed streamflow (*USGS code: 00060—Discharge, $ft^3\ s^{-1}$*) and event-based TP concentrations (*USGS code: 00665—Phosphorus, water, unfiltered, $mg\ l^{-1}\ P$*), SRP (*USGS code: 00671—Orthophosphate, water, filtered, $mg\ l^{-1}\ P$*), SSC (*USGS code: 80154—Suspended sediment concentration, $mg\ l^{-1}$*), and streamflow (*USGS code: 00061—Discharge, instantaneous, $ft^3\ s^{-1}$*) measured at the USGS stream gauging stations and bias-corrected by Coats et al., 2016. Particulate phosphorus (PP; mg L^{-1}) is not typically measured at the USGS stream gauging stations and was calculated by subtracting SRP from TP. Since these observations were event-based, we calculated the flow-adjusted daily concentrations with the LOAD ESTimator (LOADEST; Runkel et al., 2004) model, which is a USGS model used to derive relationships between event-based streamflow and suspended sediment concentrations based on eleven pre-defined regression equations. For each watershed, we ran the LOADEST model with an automated regression model selection.

On 1 January 1997 and 31 December 2005, a few watersheds on the western side of the Lake Tahoe experienced significant rain-on-snow events that caused record peak streamflow events. For example, Blackwood Creek, USGS code 10336660, recorded 83 $m^3\ s^{-1}$ (247 mm) in 1997 and 64 $m^3\ s^{-1}$ (191 mm) in 2005 peak streamflow. Therefore, when using the entire data record generated bias model results, we ran seasonally piecewise LOADEST models for all years except for WY 1997 and WY 2006, and then separately for years WY 1997 and WY 2006. Gao et al. (2018) found that the seasonally piecewise method performed better than the year-round method in estimating monthly nitrogen loads.

Static phosphorus concentrations needed as input to the WEPPcloud interface were further calculated from the flow-weighted concentrations for each watershed. We assumed the phosphorus concentrations in the surface runoff are typical of the streamflow SRP concentrations (mg L^{-1}) during spring snowmelt (months April and May) and that the phosphorus concentrations in the baseflow are typical of the streamflow SRP concentrations (mg L^{-1}) in the fall (September and October). For the phosphorus concentrations in lateral flow, we averaged the SRP streamflow concentrations (mg L^{-1}) of the remaining months. We calculated the particulate phosphorus concentrations adsorbed to sediments with equation 1.

$$pSediment = \left(\frac{TP - SRP}{SSC}\right) 10^6 \tag{1}$$

where $pSediment$ is the particulate phosphorus concentration (mg kg^{-1}), calculated for May, which is the month with the highest runoff and SSC. We used the phosphorus concentrations determined from the observed data as initial input to the model and further calibrated these values to match simulated values with observed annual average flow-adjusted loads of TP, SRP, and PP.

Model parameterization for management scenario testing

For this analysis, we modeled 72 watersheds identified in Fig. 1 for 11 management scenarios, or conditions. The management parameters used to simulate these conditions are provided in Table 3.

Management conditions:

1. *Undisturbed Current Conditions.*
2. *Uniform Thinning (96% Cover)*
3. *Uniform Thinning (Cable 93% Cover)*
4. *Uniform Thinning (Skidder 85% Cover)*
5. *Uniform Prescribed Fire*
6. *Uniform Low Severity Fire*
7. *Uniform Moderate Severity Fire*
8. *Uniform High Severity Fire*
9. *Simulated Wildfire – FCCS fuels – current conditions*
10. *Simulated Wildfire – future fuels from LANDIS and current climate*
11. *Simulated Wildfire – future fuels from LANDIS and future climate scenario A2*

The purpose for simulating undisturbed conditions was to establish a baseline for sediment and phosphorus that managers could use for comparing impacts of alternative management strategies to current conditions. For those watersheds that were gauged, the undisturbed conditions also provided an opportunity to more finely calibrate the model. The vegetation types for the current conditions assumed 100% ground cover in forested areas and 90% in the shrub-dominated areas.

Thinning and burning scenarios were simulated assuming the entire watershed was exposed to the same condition at once, although it is improbable that a fire would uniformly burn an entire watershed or that thinning would occur on all hillslopes at once. Thinning assumed 96, 93, and 85% ground cover in forested areas, with no treatment in other vegetation types. While the method of thinning does not necessarily affect the number of trees removed, it does affect the post-disturbance ground cover. We assumed the three thinning scenarios to be representative of hand thinning (96% post-disturbance ground cover), cable thinning (93%), and skidder thinning (85%), respectively. Of all thinning methods, hand thinning has the lowest ground cover disturbance. In Lake Tahoe, this method has been applied mainly on steep slopes, where there are concerns with soil disturbance by heavy equipment (Lake Tahoe Basin Report, 2014). Mechanical thinning is more cost-effective than hand thinning, however it is prohibited in the basin on slopes greater than 30 percent and on sensitive areas (e.g. stream environment zone). We also assumed the 96% mechanical treatment to be similar to cable-based thinning methods while 85% to be similar to skidder thinning. Most thinning treatments in the basin are already designed to minimize soil disturbance and, across the basin, average post-thinning ground cover varies between 87 and 100% (Norman et al., 2008, Pell and Gross, 2016, Christensen and Norman, 2007). Therefore, we considered the 85% post-disturbance ground cover as an extreme thinning scenario, which we used in several statistical analyses.

Prescribed fire, low, moderate, and high severity fire management conditions assumed ground covers of 85, 80, 60, and 30%, respectively, in forested areas, 75, 70, 50, and 30%, respectively, in shrub-dominated areas, and no treatment in other vegetation types. Similar to the thinning scenarios, the uniform application of a scenario tends to increase the overall sediment yield at the outlet of a watershed, but it allowed us to directly compare simulated runoff, sediment, and phosphorus for each hillslope and watershed from all management conditions.

The runs with a simulated wildfire were based on predicted Soil Burn Severity (SBS) map. These maps assign either a low, moderate or high soil burn severity to each hillslope in the basin and were created based on a machine learning technique in which we used historic SBS maps from the King, Angora, and Emerald fires with several environmental variable related to soils, topography, climate, landcover, and fuels, to predict SBS classes of low moderate, and high severity for the entire Lake Tahoe Basin. The fuel loads were based on both FCCS and LANDIS. FCCS is the "Fuel Characteristic Classification System" (Ottmar et al., 2007) and LANDIS is a vegetation growth model that can be driven by historic or future climates (Scheller et al. 2007).

Soil properties vary with soil type (e.g. granitic, volcanic) and land use (e.g. forest, shrubs, grass) and they change with changes in land management or with wildfire. To reflect a change in management, such as thinning, prescribed fire, or a wildfire, we altered key soils and management parameters based on filed validated measures (Elliot, 2004) (Table 3).

For this study we delineated 72 watersheds that drain directly into the lake, but only 17 watersheds have water quality observations for calibration. The k_b and k_s, channel τ_c, and phosphorus concentrations in surface runoff, subsurface lateral flow, baseflow, and sediment for the calibrated watershed runs were distributed to uncalibrated watersheds across the basin based on the watershed's similarities, parent material, and proximity.

All simulations were performed using Python batch processing scripts that generate WEPPcloud compatible projects and results were further compiled in tabular data files and GIS data files. In the current version of the WEPPcloud interface, users can perform similar scenario testing for only individual watersheds, however, future interface developments will allow select users to perform similar batch hydrologic modeling for multiple watersheds and scenarios at the same time.

Table 3. Key hillslope soils and management parameters used to parameterize the WEPPcloud interface by management and three soil types, for the study watersheds.

		Soils			Managements		
Soil Type	**Management Name**	**Critical Shear (Pa)**	**Interrill Erodibility (Kg s/m4)**	**Rill Erodibility (s/m)**	**Canopy Cover (fraction)**	**Interril Cover (fraction)**	**Rill Cover (fraction)**
Granitic	Old Forest	4	250000	0.00015	0.9	1	1
Granitic	Young Forest	4	400000	0.0002	0.8	1	1
Granitic	Forest Thinning 96% cover	4	400000	0.00004	0.4	0.96	0.96
Granitic	Forest Thinning 93% cover	4	400000	0.00004	0.4	0.93	0.93
Granitic	Forest Thinning 85% cover	4	400000	0.00004	0.4	0.85	0.85
Granitic	Forest Prescribed Fire	4	1000000	0.0003	0.85	0.85	0.85
Granitic	Forest Low Severity Fire	4	1000000	0.0003	0.75	0.8	0.8
Granitic	Forest Moderate Severity Fire	4	1000000	0.0003	0.4	0.5	0.5
Granitic	Forest High Severity Fire	4	1800000	0.0005	0.2	0.3	0.3
Granitic	Shrubs	4	141100	0.0000873	0.7	0.9	0.9
Granitic	Shrub Prescribed Fire	4	170100	0.000149	0.7	0.75	0.75
Granitic	Shrub Low Severity Fire	4	170100	0.000149	0.5	0.7	0.7
Granitic	Shrub Moderate Severity Fire	4	170100	0.000149	0.3	0.5	0.5
Granitic	Shrub High Severity Fire	4	948600	0.0004343	0.05	0.3	0.3
Granitic	Bare Slope	4	300000	0.005	0.05	0.2	0.2
Granitic	Sod Grass	4	196700	0.0004446	0.4	0.6	0.6
Granitic	Bunch Grass	4	196700	0.0004446	0.6	0.8	0.8
Alluvial	Old Forest	1	300000	0.0001	0.9	1	1
Alluvial	Young Forest	1	500000	0.00015	0.8	1	1
Alluvial	Forest Thinning 96% cover	1	500000	0.00003	0.4	0.96	0.96
Alluvial	Forest Thinning 93% cover	1	500000	0.00003	0.4	0.93	0.93
Alluvial	Forest Thinning 85% cover	1	500000	0.00003	0.4	0.85	0.85
Alluvial	Forest Prescribed Fire	1	1500000	0.0002	0.85	0.85	0.85
Alluvial	Forest Low Severity Fire	1	1500000	0.0002	0.75	0.8	0.8
Alluvial	Forest Moderate Severity Fire	1	1500000	0.0002	0.4	0.5	0.5
Alluvial	Forest High Severity Fire	1	2000000	0.0004	0.2	0.3	0.3
Alluvial	Shrubs	1	141100	0.0000873	0.7	0.9	0.9
Alluvial	Shrub Prescribed Fire	1	170100	0.000149	0.7	0.75	0.75
Alluvial	Shrub Low Severity Fire	1	170100	0.000149	0.5	0.7	0.7
Alluvial	Shrub Moderate Severity Fire	1	170100	0.000149	0.3	0.5	0.5
Alluvial	Shrub High Severity Fire	1	948600	0.0004343	0.05	0.25	0.25
Alluvial	Bare Slope	1	750000	0.004	0.05	0.2	0.2
Alluvial	Sod Grass	1	196700	0.0004446	0.4	0.6	0.6

Alluvial	Bunch Grass	1	196700	0.0004446	0.6	0.8	0.8
Volcanic	Old Forest	1.5	300000	0.00005	0.9	1	1
Volcanic	Young Forest	1.5	600000	0.0001	0.8	1	1
Volcanic	Forest Thinning 96% cover	1.5	600000	0.00002	0.4	0.96	0.96
Volcanic	Forest Thinning 93% cover	1.5	600000	0.00002	0.4	0.93	0.93
Volcanic	Forest Thinning 85% cover	1.5	600000	0.00002	0.4	0.85	0.85
Volcanic	Forest Prescribed Fire	1.5	1000000	0.0002	0.85	0.85	0.85
Volcanic	Forest Low Severity Fire	1.5	1000000	0.0002	0.75	0.8	0.8
Volcanic	Forest Moderate Severity Fire	1.5	1000000	0.0002	0.4	0.5	0.5
Volcanic	Forest High Severity Fire	1.5	1500000	0.0003	0.2	0.3	0.3
Volcanic	Shrubs	1.5	134500	0.0000846	0.7	0.9	0.9
Volcanic	Shrub Prescribed Fire	1.5	162200	0.0001444	0.7	0.75	0.75
Volcanic	Shrub Low Severity Fire	1.5	162200	0.0001444	0.5	0.7	0.7
Volcanic	Shrub Moderate Severity Fire	1.5	162200	0.0001444	0.3	0.5	0.5
Volcanic	Shrub High Severity Fire	1.5	904400	0.0004209	0.05	0.3	0.3
Volcanic	Bare Slope	1.5	600000	0.003	0.05	0.2	0.2
Volcanic	Sod Grass	1.5	187600	0.0004309	0.4	0.6	0.6
Volcanic	Bunch Grass	1.5	187600	0.0004309	0.6	0.8	0.8

Basin-scale statistical analyses

Management scenario comparison

After running the WEPPcloud interface for all watersheds in the basin, and for all 11 conditions, we saved the model outputs, including information regarding elevation, slope, aspect, soil properties, landuse, etc. for each modeled hillslope as shapefiles and tables. We further plotted the data and performed calculations and statistical analyses to compare soil erosion between the different management conditions as well as to better understand the drivers for sediment and phosphorus yield.

To compare the potential soil erosion changes from the management scenarios we calculated annual average sediment yield by each treatment. A histogram of the data indicates that non-zero sediment yield are highly skewed and appear to fit a log normal distribution (Fig. 3). Therefore, this analysis used the data filtered to non-zero sediment yield, as zero values within a dataset make linear modelling difficult. Additionally, only observations with non-zero sediment yield are informative. Since we are only using a subset of the data, this is a conditional analysis.

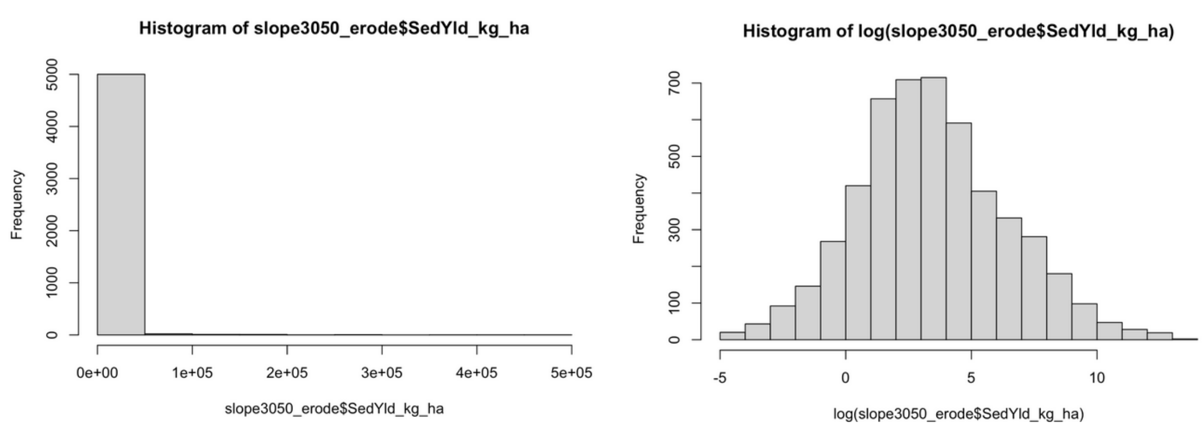

Fig. 3. Histogram of sediment yield for hillslopes between 30-50% that erode. Untransformed data (left) and log-transformed data (right).

Estimating Treatment Benefits

One approach to evaluating the impacts of thinning is to compare the erosion associated with thinning as an absolute difference in sediment yield from thinning as compared to current conditions by hillslope (Eq. 1). These calculations were performed on the hillslope output data and then mapped for the Blackwood Watershed, which we used as an example. For all these calculations we used the thinning scenario with the 85% post-treatment ground cover. Since post-thinning ground cover in Lake Tahoe Basin often exceeds 85% (Norman et al., 2008, Pell and Gross, 2016, Christensen and Norman, 2007), we consider the thin 85% a worst-case thinning scenario.

Eq. 1

$$AbsoluteDifference = Thinning85cover - CurrentErosion$$

Thinning forested hillslopes can reduce fire severity. However, thinning can also increase erosion compared to undisturbed or current conditions. We estimated a treatment benefit based on four of the modeled conditions (unburned, thin 85%, low severity and moderate severity). The estimated erosion rates would generally occur in the year of the disturbance. Most forested watersheds recover quickly from disturbances associated with low severity fire or thinning. We selected the thinning scenario with the most post-disturbance ground cover (85% cover) and assumed that by thinning, the burn severity would be reduced from a moderate severity to the low severity. We also assumed that thinning would be carried out three times as often as a wildfire would occur, for example every 20 years for thinning instead of every 60 years for wildfire. We selected a thinning regime of 20 years because it is common practice in the basin; however, we also tested treatment benefits by thinning 1, 10, 20, 30, 40, 50, and 60 times within the 60 years fire return interval.

We then defined and calculated the Treatment Benefit as:

Eq. 2

$$TreatmentBenefit = (ModerateSeverity - LowSeverity) - ((Thinning85 - CurrentConditions)x3)$$

Treatment effects on sediment yield for slopes 30–50%

Specifically, we were interested in sediment and phosphorus yield following thinning on steeper slopes (30–50%) since these hillslopes are now considered for mechanical thinning by managers looking to reduce ground fuels to minimize wildfire risks.

We further tested the change in probability of eroding versus not eroding for different treatments. We accomplished this by calculating odds ratios and risk ratios, for all hillslopes with sediment yield > 0 kg/ha and between 30–50% slopes. In this analysis, we only considered three thinning scenarios, the prescribed fire scenario, and the high severity wildfire scenario as a worst-case scenario. The *odds* *ratio* indicates the change of odds of erosion versus no erosion under current conditions compared to the other treatments. The *risk ratio,* slightly different from the odds ratio, calculates the risk of erosion for the entire population of each scenario. Like the odds ratio, it is comparing the ratio between the reference level, current conditions, fire, and thinning scenarios. The results are otherwise interpreted the same as an odds ratio.

Lastly, we ran a *Generalized Linear Model* (GLM) of scenario versus sediment yield using a log-normal distribution The results of the Analysis of Variance (ANOVA) are presented along with pairwise comparison between each treatment and the current conditions (which is treated as a reference level in the analysis).

Variable importance

In addition to the data analysis presented so far, we also performed several exploratory data analyses such as Correlations, Principal Component Analysis (PCA)**,** and Random Forest (RF). These analyses were performed on various environmental variables extracted by hillslope from the WEPP model input data.

Correlations, specifically spearman correlations, were performed by first considering all the forested hillslopes in the basin, and then by some of the most eroding forested watersheds (i.e. Blackwood Creek, Ward Creek, Trout, and Upper Truckee). All correlations were performed with the statistical software R with the package *psych* at $\alpha \leq 0.001$.

PCA is a multivariate statistical data analysis that is used to reduce a large number of correlated variables into uncorrelated variables, named principal components, and to infer underlying relationships between the set of variables. In general, PCA provides an understanding of:

1. The relationship between the variables;
2. The direction in which data are dispersed; and
3. The relative importance of each direction.

Variables that point in the same direction are positively correlated while those that point in opposite directions are negatively correlated. Variables that are perpendicular are not correlated.

We used a PCA analysis to explore the distribution of sediment yield relative to several soil and topographical variables. For displaying purposes, a categorical variable *SedYld_Class* was created by binning sediment yield into 3 categories: no erosion, low erosion, and high erosion. The cutoff between low erosion and high erosion categories was set to split the data in relatively equal parts. We created PCA plots based on the forested hillslopes for each management condition.

RF or random decision forest is a type of machine learning algorithm used for classification or regression of multiple variables within a dataset. We used the RF algorithms to predict if a hillslope will erode or not and also to predict the hillslope sediment yield for current conditions, 85% thinning, prescribed fire, and high severity fire based on multiple physical attributes. The “observed” sediment yield in this case was the WEPP modeled sediment yield at each hillslopes. While this approach is redundant (i.e. predicting soil erosion already predicted by WEPP), we were mainly interesting in identifying physical hillslope attributes that explain the variability in soil erosion.

To predict if a hillslope will erode or not, we created a new variable *SedVar* by converting sediment yield to a binary variable where any data point greater than zero was classified as "eroded" and all data points equal to zero were classified as "non-eroded". To predict the actual values of sediment yield, we used the WEPP-predicted sediment yield resulted from the four management scenarios: current conditions, thinning 85%, prescribed fire, and high severity fire.

IV. RESULTS AND DISCUSSION

Model performance assessment

Streamflow and water yield assessment

The WEPP model was applied to 17 watersheds of varying sizes in the Lake Tahoe Basin. The overall goodness-of-fit statistics for the WEPP-simulated and observed daily streamflow comparisons for the watersheds indicate reasonable results (Table 4). Across the watersheds, *NSEs* based on daily streamflow values were in the range of 0.44 to 0.64 indicating satisfactory agreement between modeled and observed values. The only exception was the Logan House Creek watershed (LH1), located on the eastern side of the Lake Tahoe Basin, with an *NSE* of −0.09 signifying poor model performance. Brooks et al. (2016) reported similar results for the LH1 watershed, which the authors attributed to water loss through fractures in the bedrock. The WEPP model was not able to simulate this complex hydrogeology without additional calibration. Positive *KGE* values in the range of 0.56 to 0.78 (excluding watershed LH1) suggest reasonable model performance when considering mean flow as a *KGE* estimation criterion. *Pbias* within ± 3.81% across all watersheds indicated slight over- and under-prediction of streamflow (Table 4).

The WEPP model captured runoff regimes across all watersheds reasonably well, and the simulated annual trends of water yield followed the trends of observed yield (Fig. 4 and 5). Compared to daily streamflow, monthly and annual goodness-of-fit statistics showed improved model performance for all watersheds (Table 4).

Table 4. Goodness-of-fit statistics for observed and simulated streamflow simulations. D = daily, M = monthly, A = annually (Water Year) statistics.

No.	Name	Begin	End	*NSE*			*KGE*			*PBias (%)*		
				D	***M***	***A***	***D***	***M***	***A***	***D***	***M***	***A***
						California						
1	WC8	1/1/1990	9/30/2014	0.59	0.69	0.94	0.60	0.72	0.84	4.5	4.8	4.5
2	WC7A	10/1/1991	9/30/2001	0.59	0.71	0.98	0.62	0.77	0.92	0.3	0.4	0.3
3	WC3A	10/1/1991	11/1/2011	0.61	0.71	0.96	0.65	0.73	0.94	0.3	0.5	0.3
4	BC1	1/1/1990	9/30/2014	0.59	0.66	0.94	0.61	0.69	0.85	0.1	0.3	0.1
5	GC1	1/1/1990	9/30/2014	0.54	0.61	0.90	0.66	0.71	0.89	10.7	11	10.7
6	UTR1	1/1/1990	9/30/2014	0.53	0.63	0.91	0.73	0.78	0.86	12.8	13.1	12.8
7	UTR3	6/1/1990	9/30/2012	0.56	0.66	0.96	0.77	0.82	0.9	6.3	6.4	6.3
8	UTR5	5/12/1990	10/11/2011	0.59	0.73	0.93	0.78	0.83	0.84	−7.7	−7.8	−7.7
9	TC4	1/1/1990	9/30/2014	0.64	0.69	0.86	0.75	0.77	0.74	−9.9	−9.8	−9.9
10	TC2	6/1/1990	9/30/2012	0.54	0.60	0.92	0.77	0.79	0.84	−6.8	−6.8	−6.8
11	TC3	5/22/1990	3/31/2011	0.48	0.53	0.87	0.67	0.69	0.76	0.3	0.3	0.3
						Nevada						
12	LH1	1/1/1990	10/12/2011	−0.09	0.49	0.77	0.39	0.48	0.62	−3.2	−3.1	−3.2
13	GL1	1/1/1990	9/30/2012	0.53	0.66	0.87	0.56	0.60	0.77	2.8	2.8	2.8
14	IN1	1/1/1990	9/30/2014	0.44	0.57	0.72	0.56	0.56	0.60	−3.2	−3.2	−3.2
15	IN2	1/1/1990	9/30/2004	0.48	0.65	0.81	0.62	0.61	0.70	−2.2	−2.2	−2.2
16	IN3	5/1/1990	3/31/2011	0.48	0.71	0.80	0.69	0.66	0.68	−1.5	−1.4	−1.5
17	TH1	1/1/1990	9/30/2014	0.60	0.82	0.86	0.76	0.89	0.87	0	−0.1	0
	Mean§			**0.55**	**0.66**	**0.89**	**0.68**	**0.73**	**0.81**	**3.81**	**1.40**	**3.81**

§ Mean values calculated without LH1 watershed.
See Fig. 1 for watershed location and Table A1 in Appendix for full watershed names.

Nevertheless, uncalibrated model results in this study suggest that the WEPPcloud interface can satisfactorily represent the hydrology of distinct geographic regions and that water resources managers could apply the interface to ungauged watersheds for forest management decisions. Future efforts to improve hydrologic simulations with the WEPPcloud interface are underway to improve the snow hydrology routines in WEPP.

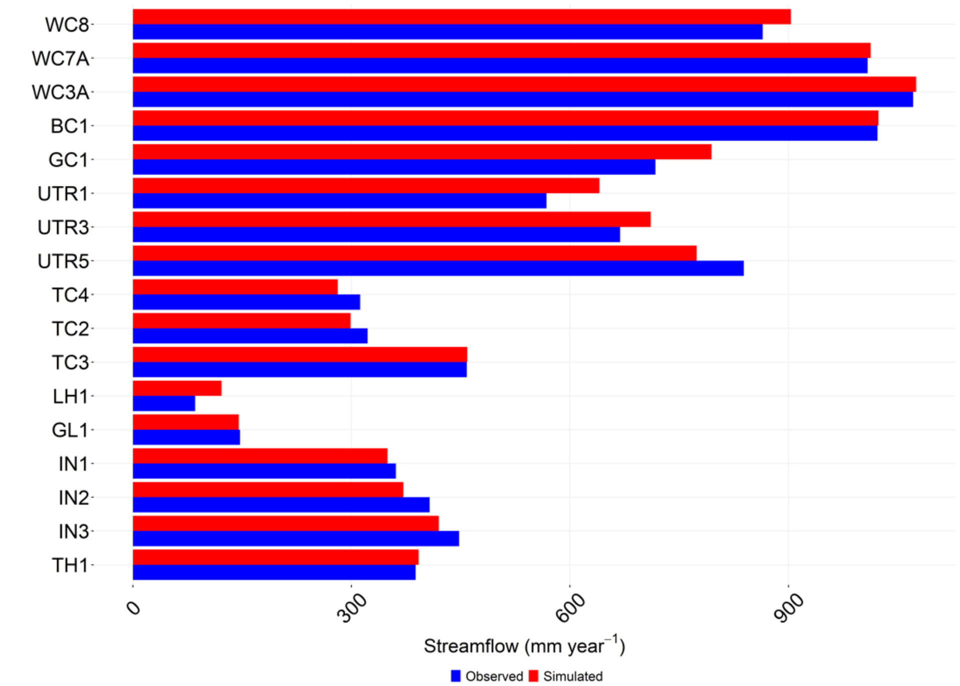

Fig. 4. Comparison of observed and simulated average annual water yield for the study watersheds.

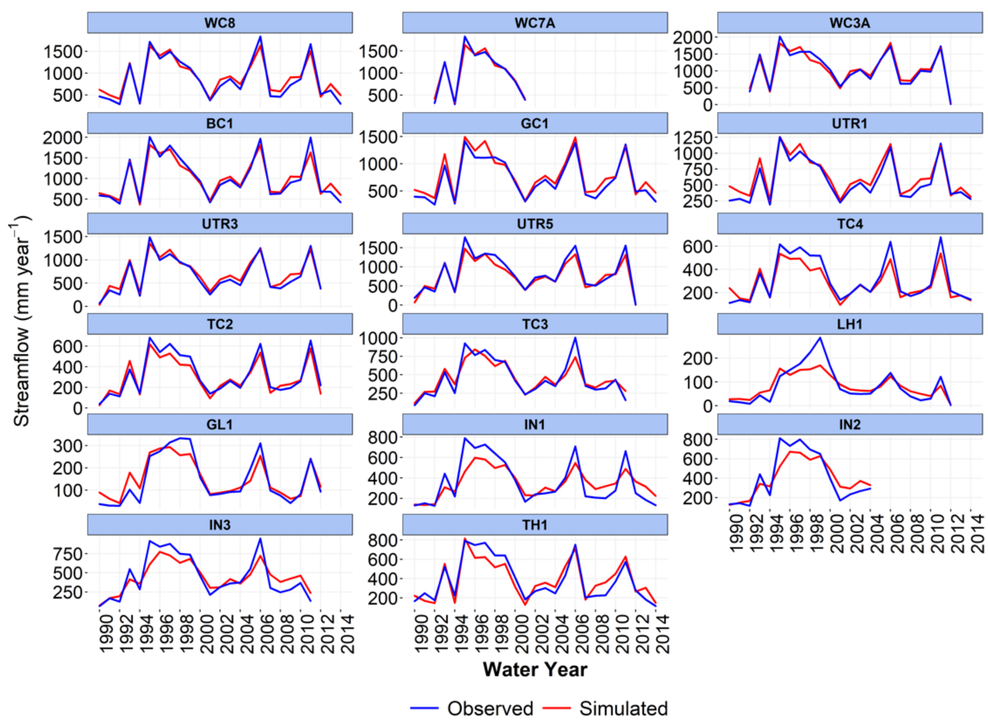

Fig. 5. Comparison of simulated and observed annual streamflow.

A linear groundwater reservoir with a default k_b of 0.04 d^{-1} was appropriate to model low summer streamflow in most watersheds of this study, except in the drier watersheds on the east-side of the basin. For these watersheds, the initial model results showed overestimations in water yield. Similar results were reported by Brooks et al. (2016) in Logan House (LH1) and Glenbrook Creek (GC1) watersheds. In their study, the authors used a secondary reservoir to simulate water yield by allowing groundwater loss through hydrogeological fractures and, therefore, bypassing the USGS stream gauge. In this study, the addition of a second aquifer reservoir in nine watersheds located in the NE, E, and SE of the Lake improved water yield simulations, supporting an okd hypothesis that these watersheds could be characterized by complex hydrogeology (Hyne et al., 1972). Calibrated k_b and k_s for all watersheds are shown in Table 5.

Table 5. Calibrated parameter values for baseflow and deep seepage coefficients, channel critical shear stress, and phosphorus concentrations in surface runoff, subsurface lateral flow, baseflow, and sediment.

No.	**Name**	**Baseflow coefficient (d^{-1})**	**Deep seepage coefficient (d^{-1})**	**τ_c (Nm^{-2})**	**P_{runoff} (mg L^{-1})**	**$P_{lateral}$ (mg L^{-1})**	**$P_{baseflow}$ (mg L^{-1})**	**$P_{sediment}$ (mg L^{-1})**
				California				
1	WC8	0.04	0	30	0.004	0.005	0.006	1300
2	WC7A	0.04	0	30	0.005	0.006	0.007	1100
3	WC3A	0.04	0	30	0.003	0.004	0.005	900
4	BC1	0.04	0	10	0.003	0.004	0.005	1100
5	GC1	0.04	0	45	0.002	0.003	0.004	1300
6	UTR1	0.04	0	15	0.004	0.005	0.006	1200
7	UTR3	0.04	0	70	0.003	0.004	0.005	1300
8	UTR5	0.04	0	180	0.007	0.008	0.009	1300
9	TC4	0.01	0.0062	45	0.008	0.009	0.010	1800
10	TC2	0.0168	0.0105	45	0.008	0.009	0.010	1700
11	TC3	0.01	0.0010	75	0.007	0.008	0.009	1500
				Nevada				
12	LH1	0.0005	0.0009	40	0.001	0.002	0.003	2500
13	GL1	0.0018	0.0016	35	0.015	0.016	0.017	3500
14	IN1	0.0019	0.0010	35	0.011	0.012	0.013	1500
15	IN2	0.0017	0.0006	40	0.011	0.012	0.013	1300
16	IN3	0.0022	0.0009	45	0.010	0.011	0.012	1300

17	TH1	0.0130	0.0134	25	0.008	0.009	0.010	700

See Fig. 1 for watershed location and Table A1 in Appendix for full watershed names.

Sediment load

Observed annual average sediment loads generally varied between the west- and the east-side, and from watershed to watershed. Eastern watersheds generated considerably less sediment compared to watersheds from the western side of the basin. Observed annual average sediment loads ranged from 5 Mg yr^{-1} at Logan House Creek (LH1) to 2852 Mg yr^{-1} from Blackwood Creek (BC1). This difference is mainly due to differences in area and precipitation since the LH1 watershed received less than half of the precipitation recorded in the BC1 (657 mm yr^{-1} precipitation in LH1 compared to 1476 mm yr^{-1} recorded in BC1; Table 2). Other watershed characteristics such as watershed soils, geology, and vegetation, may also contribute to the difference in sediment loads between the two watersheds, albeit to a lesser extent.

Model results showed an underestimation of annual sediment loads at three watersheds in the western side of the basin, namely at Blackwood Creek (BC1), Ward Creek (WC8), and General Creek (GC1) (Figs. 6 and 7). The main reason for this underestimation was due to sediment delivery associated with a few high peak flow events from 1 and 2 January 1997 (WY 1997) and on 31 December 2005 (WY 2006), which were not captured by the model. These high peak flow rates were caused by rain-on-snow events that are often observed in the mid-winter in Pacific Northwest (Marks et al., 2001) and in watersheds in the Sierra Nevada mountains (Kattelmann, 1997; McCabe et al., 2007). In the Lake Tahoe Basin, the 1997 event was considered a 100-year flood event (Tetra Tech, 2007), which caused peak suspended sediment loads with return periods ranging from 40 to 60 years only in streams from the western side of Lake Tahoe (Simon et al., 2004). Brooks et al. (2016) demonstrated that the WEPP model can accurately simulate the 1997 high peak flow in the Upper Truckee River (UTR5) when scaling the weather data across the watershed based on data from a lower elevation SNOTEL station, which recorded a slightly different rain distribution for the day. Since most of the sediment is delivered during these high peak flow events, an accurate representation of weather data is essential to model such events.

Another potential source of underestimation of sediment load by WEPP may be sediment delivery from landslides, as the WEPP model does not consider mass wasting sources of sediment. There is some evidence of mass wasting, particularly in the steeper upland portions of the Blackwood Creek (BC1) watershed (Gavigan, 2007). Additional sediment during peak flows may also be from channel erosion processes not addressed by the WEPP model, like side sloughing during channel drawdown following flood flows that would have saturated the stream banks (Simon et al. 2009).

The goodness-of-fit statistics based on annual sediment loads for all simulated years show that WEPP predictions were in reasonable agreement with observed data except for WC8, BC1, and GC1 watersheds (Table 6). Results for the three watersheds improved substantially when the water years with high peak flow events (1997 and 2006) were omitted from the analysis. For example, *NSE*, *KGE*, and *Pbias* for watershed BC1 improved from 0.05 to 0.63, −0.15 to 0.48, and −60% to −7%, respectively.

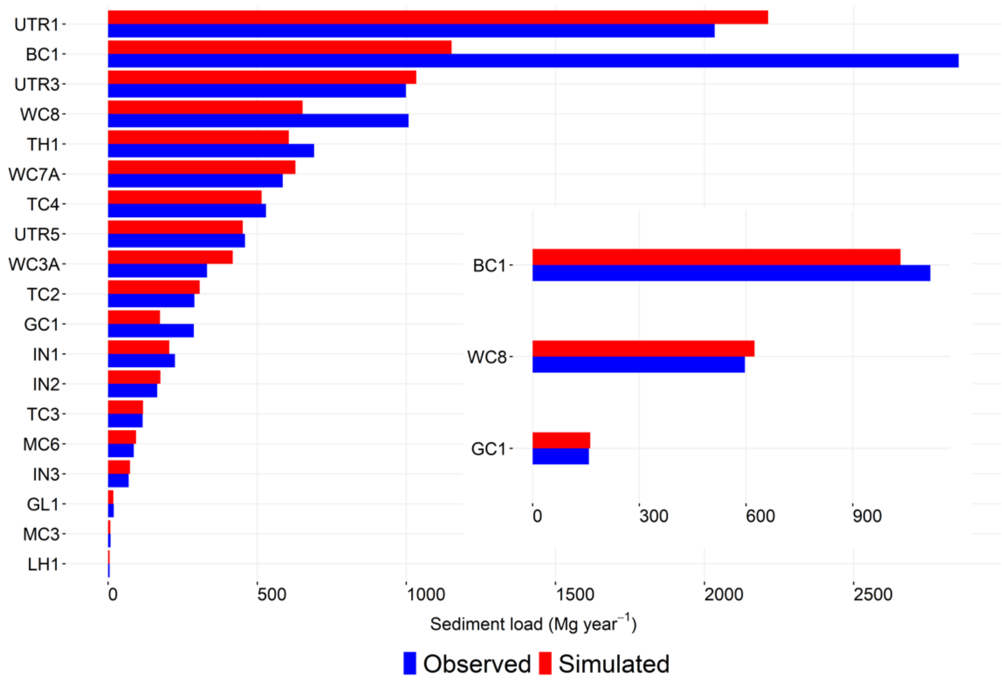

Fig. 6. Comparison of WEPP-simulated and observed average annual sediment load. WEPP underestimated sediment loads in the three watersheds (WC8, BC1, and GC1) that were affected by the rain-on-snow events in WY 1997 and 2006. The inset figure shows WEPP-simulated and observed sediment load after excluding these two years.

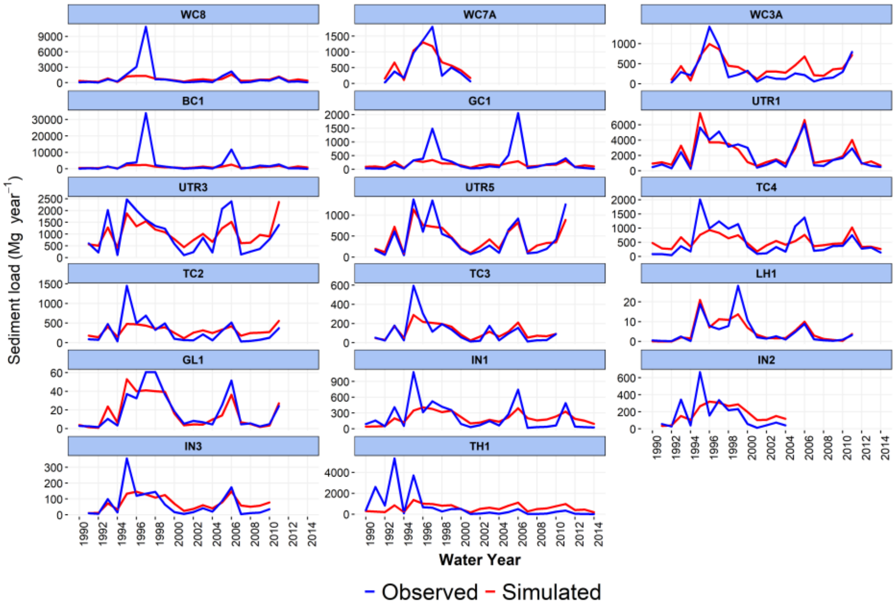

Fig. 7. Comparison of WEPP-simulated and observed annual sediment load.

Table 6. Goodness-of-fit statistics for the WEPP-simulated and observed annual sediment load. Italicized rows denote watersheds where statistics were recalculated after eliminating sediment load in 1997 and/or 2006 water years that experienced high peak flow events and extreme soil erosion.

No.	***Name***	***nPairs***	***NSE***	***KGE***	***PBias (%)***
			California		
1	WC8	25	0.16	0.03	–35.3
1	*WC8*†	*25*	*0.62*	*0.48*	*4.6*
2	WC7A	10	0.78	0.70	7.2
3	WC3A	20	0.67	0.60	26
4	BC1	25	0.05	–0.15	–59.6
4	*BC1*††	*25*	*0.63*	*0.48*	*–7.2*
5	GC1	25	0.15	0.03	–39.4
5	*GC1*††	*25*	*0.58*	*0.49*	*1.9*
6	UTR1	25	0.82	0.88	8.8
7	UTR3	21	0.60	0.56	3.5
8	UTR5	21	0.80	0.70	–1.7
9	TC4	25	0.47	0.38	–2.8
10	TC2	21	0.41	0.32	6.1
11	TC3	20	0.65	0.53	0.9
			Nevada		
12	LH1	22	0.73	0.74	–2.2
13	GL1	22	0.79	0.81	–6.6
14	IN1	25	0.43	0.36	–8.3
15	IN2	14	0.36	0.39	6.4
16	IN3	20	0.51	0.45	7.2
17	TH1	25	0.12	0.02	–12.4
	Mean§		**0.59**	**0.52**	**5.95**

† *Calculations without WY 1997.*

[††] Calculations without WY 1997 and 2006.
[§] Mean values calculated without WY 1997 and WY 2006 for WC8, BC1, and GC1.
See Fig. 1 for watershed location and Table A1 in Appendix for full watershed names.

We manually calibrated the τ_c in the Lake Tahoe watersheds to match the simulated to observed annual sediment loads at the watershed outlets, assuming minimal upland erosion. These values ranged from 10 Nm^{-2} in the Blackwood Creek watershed to 180 Nm^{-2} in the headwaters of the Upper Truckee River (UTR5) watershed (Table 5). Lower values of the τ_c are associated with smaller D_{50} particle size (Srivastava et al., 2020), and therefore higher soil erodibility for channel beds. Conversely, higher values of τ_c are associated with larger D_{50} particle sizes and result in lower erodibility values. Indeed, the Blackwood Creek watershed is known in the Lake Tahoe Basin as the top contributor of sediment yield to the lake and has been the subject of several channel restoration efforts (Norman et al., 2014; Oehrli, 2013). The headwater portion of the Upper Truckee River watershed is characterized by rock outcrops of low infiltration rates and erodibilities (Brooks et al., 2016), which can be an explanation for the higher τ_c calibrated by the model. Median pebble count data (D_{50}) was available for two of the modeled watersheds in the Lake Tahoe Basin and τ_c equivalents for these two watersheds approximately matched the calibrated values $\tau_{c\text{-calibrated}}$: Blackwood Creek, mainstream, D_{50} = 42, τ_c = 26, $\tau_{c\text{-calibrated}}$ = 10; Ward Creek, D_{50} = 68 τ_c = 54, $\tau_{c\text{-calibrated}}$ = 30.

Phosphorus yield

The magnitudes of all three phosphorus constituents simulated by the WEPP model were in close agreement with the observed across all watersheds (Figs. 8a and 8b). The goodness-of-fit statistics based on annual values were very good for all three phosphorus constituents (Table 7): TP (*NSE* = 0.75, *KGE* = 0.71, *PBias* = −0.5%), PP (*NSE* = 0.71, *KGE* = 0.70, *PBias* = −1.3%), and SRP (*NSE* = 0.66, *KGE* = 0.66, *PBias* = −4.6%). The simulated annual loads of TP, PP, and SRP followed the trends of observed load (data not shown), which is expected since PP, which is transported mainly with sediments, is the major form of phosphorus transport in streams from Lake Tahoe (Hatch et al., 2001). Therefore, similar to the sediment load, the TP and PP load for the three watersheds (WC8, BC1, and GC1) that experienced the rain-on-snow events in WY 1997 and 2006 were also underestimated (Figure 8a). Simulated annual SRP load was better captured by the model, except in Logan House (LH1) where the model underestimated the observed loads (*PBias* = −95%; Table 7). However, it is worth noting that the difference between the observed and simulated phosphorus load for this watershed is insignificant (1.5 kg yr^{-1}).

The simplistic coefficient-based phosphorus algorithms implemented in the WEPPcloud interface were sufficient to capture the general trends of annual phosphorus loads associated with surface runoff, subsurface lateral flow, baseflow, and sediment in our study watersheds (Figs. 8 and 9). Most process-based phosphorus models use complex processes involving mineralization, decomposition, and immobilization pools and their interaction among them for phosphorus transport computations. Hydrologic simulations with such algorithms may improve the spatial and temporal estimates of phosphorus for watershed simulation studies. A version of the WEPP model with a water quality module is under development (personal communication, D.C. Flanagan) and would likely be available for the evaluation of nutrient transport in forest settings in the future version of WEPPcloud.

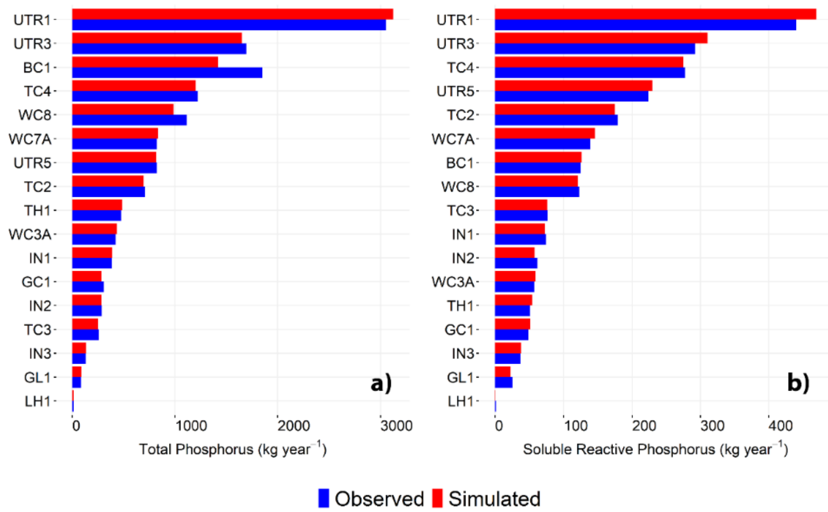

Fig. 8. Comparison of WEPP-simulated and observed average annual TP (a) and SRP (b) loads. PP exhibited similar trends as TP.

Table 7. Goodness-of-fit statistics for the average annual phosphorus load for the three constituents (TP = Total Phosphorus, PP = Particulate Phosphorus, and SRP = Soluble Reactive Phosphorus). Italicized rows denote watersheds where statistics were recalculated after eliminating phosphorus load in 1997 and/or 2006 water years that experienced high peak flow events and extreme soil erosion.

No.	**Name**		**TP**			**PP**			**SRP**		
		nPairs	***NSE***	***KGE***	***Pbias (%)***	***NSE***	***KGE***	***Pbias (%)***	***NSE***	***KGE***	***Pbias (%)***
						California					
1	WC8	25	0.56	0.43	–11.5	0.53	0.41	–12.7	0.83	0.70	–2.2
1	*WC8†*	*25*	*0.79*	*0.65*	*2.5*	*0.77*	*0.71*	*2.6*	*0.83*	*0.71*	*0.6*
2	WC7A	20	0.94	0.96	1.6	0.93	0.96	0.8	0.94	0.91	5
3	WC3A	10	0.75	0.82	2.8	0.75	0.83	2.3	0.64	0.66	3.9
4	BC1	25	0.39	0.28	–23.3	0.37	0.25	–25.2	0.69	0.67	1.2
4	*BC1††*	*25*	*0.70*	*0.63*	*0.4*	*0.69*	*0.62*	*0.3*	*0.69*	*0.62*	*0.5*
5	GC1	25	0.64	0.53	–8	0.57	0.46	–11	0.75	0.84	6.2
5	*GC1††*	*25*	*0.79*	*0.74*	*4.1*	*0.75*	*0.82*	*3.3*	*0.74*	*0.82*	*6.1*
6	UTR1	25	0.81	0.85	2.3	0.75	0.78	1.5	0.8	0.68	6.6
7	UTR3	21	0.83	0.71	–2.4	0.79	0.70	–4.3	0.77	0.69	6.3
8	UTR5	21	0.86	0.83	–0.7	0.76	0.77	–2	0.94	0.89	2.5
9	TC4	25	0.80	0.65	–1.6	0.75	0.61	–1.8	0.87	0.76	–0.9
10	TC2	21	0.70	0.55	–1.6	0.59	0.47	–1.5	0.9	0.79	–2.4
11	TC3	20	0.84	0.83	–3.3	0.81	0.81	–4.6	0.89	0.83	–0.8
						Nevada					
12	LH1	22	0.63	0.68	–21.9	0.53	0.64	–28.6	–1.17	-0.39	–94.6
13	GL1	22	0.83	0.91	3	0.75	0.81	2.3	0.77	0.79	–10.9
14	IN1	25	0.65	0.58	1.2	0.64	0.58	2.1	0.64	0.49	–2.3
15	IN2	14	0.59	0.59	–0.8	0.56	0.59	0.9	0.66	0.54	–6.2

16	IN3	20	0.82	0.79	3	0.80	0.82	2.4	0.56	0.65	2.5
17	TH1	25	0.41	0.36	2.7	0.37	0.33	1.9	0.75	0.83	5.7
	Mean[§]		**0.75**	**0.71**	**–0.51**	**0.71**	**0.70**	**–1.32**	**0.66**	**0.66**	**–4.61**

[†] *Calculations without WY 1997.*

[††] *Calculations without WY 1997 and 2006.*

[§] *Mean values calculated without WY 1997 and WY 2006 for WC8, BC1, and GC1.*

See Fig. 1 for watershed location and Table A1 in Appendix for full watershed names.

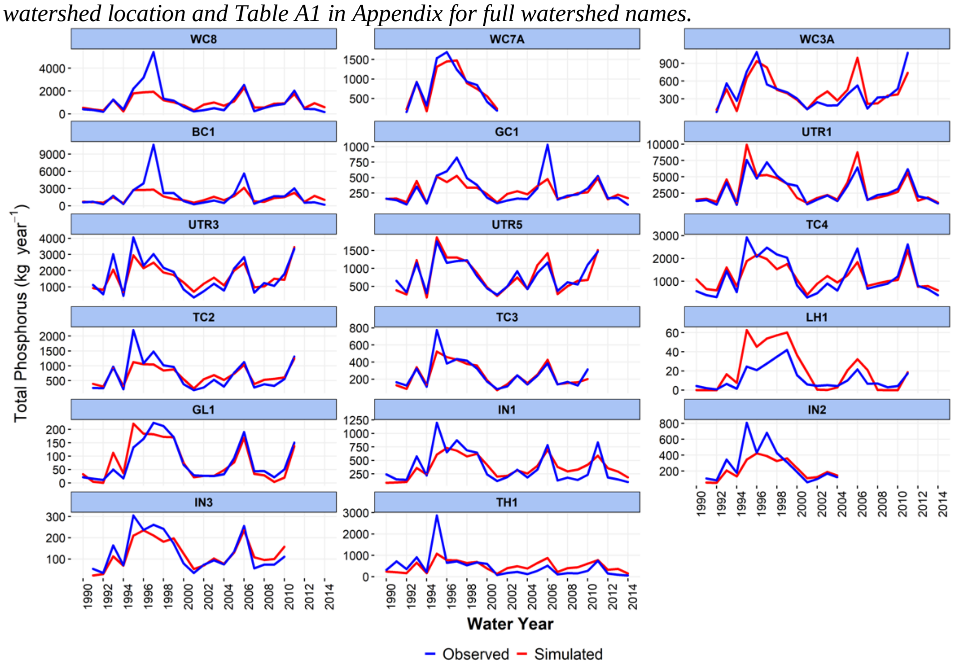

Fig. 9. Comparison of WEPP-simulated and observed annual TP loads for the Lake Tahoe Basin watersheds. SRP and PP exhibited similar trends as TP.

Phosphorus concentration values in runoff inferred from the observed data varied between 0.0028 mg L^{-1} in General Creek (GC1) to 0.013 mg L^{-1} in Glenbrook Creek (GL1). The lateral flow and baseflow P concentrations were higher than those in the runoff and ranged between 0.026 mg L^{-1} in Logan House (LH1) to 0.0153 mg L^{-1} in Glenbrook Creek (GL1) for lateral flow, and from 0.0024 mg L^{-1} in Logan House (LH1) to 0.0228 mg L^{-1} in Glenbrook Creek (GL1) for baseflow, respectively. In general, these values were lower in watersheds located on the western side and higher in those from the eastern side of the basin. The observed P concentrations in the sediments varied between 840 mg kg^{-1} in Third Creek (TH1) to 4397 mg kg^{-1} in Glenbrook Creek (GL1). Similarly, as with the streamflow P concentrations, sediment P concentrations varied among watersheds, with lower values in watersheds on the northern, western, and southern sides of the basin and higher values in watersheds from the eastern side of the basin (Table 8).

The significant difference in P concentration in runoff and sediment between watersheds on the west- and east sides of Lake Tahoe, respectively, is likely due to differences in the parent material. Specifically, watersheds located on the NW and W of Lake Tahoe are mainly underlying volcanic soils with poorly crystalline iron and aluminum oxides that retain P and limit the P movement in water

(Heron et al., 2020). Watersheds on the eastern side of the Lake Tahoe Basin, however, are developed mainly on granitic parent material with greater potential for P mobilization to streamflow (Heron et al., 2020).

Table 8. Observed (Obs.) and calibrated (Calib.) phosphorus concentrations. Observed values are inferred from the flow-weighted phosphorus and sediment concentrations calculated with the LOADEST model.

No.	Name	Single/ Double aquifer reservoir	Obs. in runoff (mg L^{-1})	Calib. in runoff (mg L^{-1})	Obs. in lateral flow (mg L^{-1})	Calib. in lateral flow (mg L^{-1})	Obs. in baseflow (mg L^{-1})	Calib. in baseflow (mg L^{-1})	Obs. in sediment (mg kg^{-1})	Calib. in sediment (mg kg^{-1})
					California					
1	WC8	Single	0.0059	0.004	0.009	0.005	0.0125	0.006	2059	1300
2	WC7A	Single	0.0053	0.005	0.009	0.006	0.0147	0.007	1188	1100
3	WC3A	Single	0.0034	0.003	0.004	0.004	0.0045	0.005	1600	900
4	BC1	Single	0.0040	0.003	0.007	0.004	0.0116	0.005	1166	1100
5	GC1	Single	0.0028	0.002	0.009	0.003	0.0187	0.004	1303	1300
6	UTR1	Single	0.0049	0.004	0.006	0.005	0.0070	0.006	1362	1200
7	UTR3	Single	0.0034	0.003	0.004	0.004	0.0050	0.005	1896	1300
8	UTR5	Single	0.0052	0.007	0.010	0.008	0.0209	0.009	2466	1300
9	TC4	Double	0.0073	0.008	0.008	0.009	0.0094	0.01	2966	1800
10	TC2	Double	0.0080	0.008	0.009	0.009	0.0099	0.01	1789	1700
11	TC3	Double	0.0077	0.007	0.009	0.008	0.0104	0.009	2545	1500
					Nevada					
12	LH1	Double	0.0037	0.002	0.003	0.003	0.0024	0.004	3875	2300
13	GL1	Double	0.0130	0.015	0.015	0.016	0.0228	0.017	4397	3500
14	IN1	Double	0.0109	0.011	0.012	0.012	0.0141	0.013	1727	1500
15	IN2	Double	0.0123	0.011	0.012	0.012	0.0120	0.013	1248	1300
16	IN3	Double	0.0104	0.01	0.011	0.011	0.0127	0.012	2280	1300
17	TH1	Double	0.0080	0.008	0.011	0.009	0.0138	0.01	840	700
	Mean	**Single**	**0.004**	**0.004**	**0.007**	**0.005**	**0.012**	**0.006**	**1630**	**1188**
	Mean	**Double**	**0.009**	**0.009**	**0.010**	**0.010**	**0.012**	**0.011**	**2407**	**1733**

Observed in runoff: Average SRP concentrations for April and May.
Observed in lateral flow: Average SRP concentrations of all months, except April, May, September, and October.
Observed in baseflow: Average SRP concentrations for September and October.
Observed in sediment: Average (TP-SRP) x 10^6 /SSC for May.
See Fig. 1 for watershed location and Table A1 in Appendix for full watershed names.

Basin-scale model runs

The model calibration for the 17 watersheds in the basin allowed us to identify the minimum number of critical calibrating parameters in the model to confidently simulate streamflow, and sediment and phosphorus yield. Model results suggested that most of the calibrated parameters are fairly consistent across each ecosystem where a calibrated value in one watershed is also reasonable for a neighboring watershed in the same ecosystem. For example, eight watersheds in the western side of the basin were calibrated with a single linear reservoir aquifer and a baseflow recession coefficient of 0.04 day^{-1}. Conversely, all watersheds located NE, E, and SE were calibrated with a second linear reservoir and various deep seepage coefficients. These similarities among watersheds allowed us to apply the calibrated values to model the rest of the ungauged watersheds within the basin. Regional differences were also observed for the channel critical shear and phosphorus concentrations, which were similarly distributed across the basin (Figs A1, A2, A3).

WEPPcloud simulated output can be downloaded as summarized tables and GIS shapefiles (Fig. 10) and managers can use this information to compare runoff, sediment yield, and phosphorus yields from individual hillslopes and watersheds (https://wepp.cloud/weppcloud/lt/). For example, maps of sediment yield output suggest that under undisturbed conditions there are erosion hot spots within several watersheds in the basin (e.g. Blackwood Creek, Ward Creek, upland portion of the Upper Truckee River, and Third Creek) and that sediment yield from these areas tends to increase with disturbance severity (Fig. 11). Another observation with great implications for management is that for the eastern watersheds, the model simulated minimal to no erosion even after a wildfire (< 1 kg ha^{-1}). Two of the eastern watersheds have been identified in previous research studies as sinks, rather than sources of sediments mainly due to their small size and low precipitation and runoff rates (Simon et al., 2004). This finding could be useful to prioritize areas for treatment in the basin.

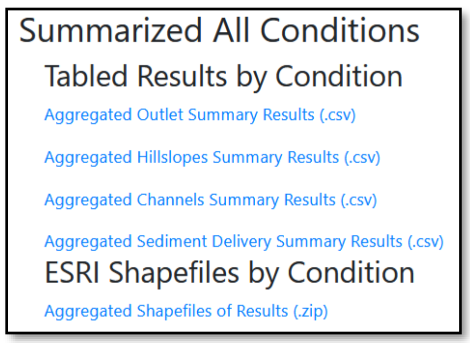

Fig. 10. Summarized results for all watersheds in the Lake Tahoe available on the WEPPcloud interface.

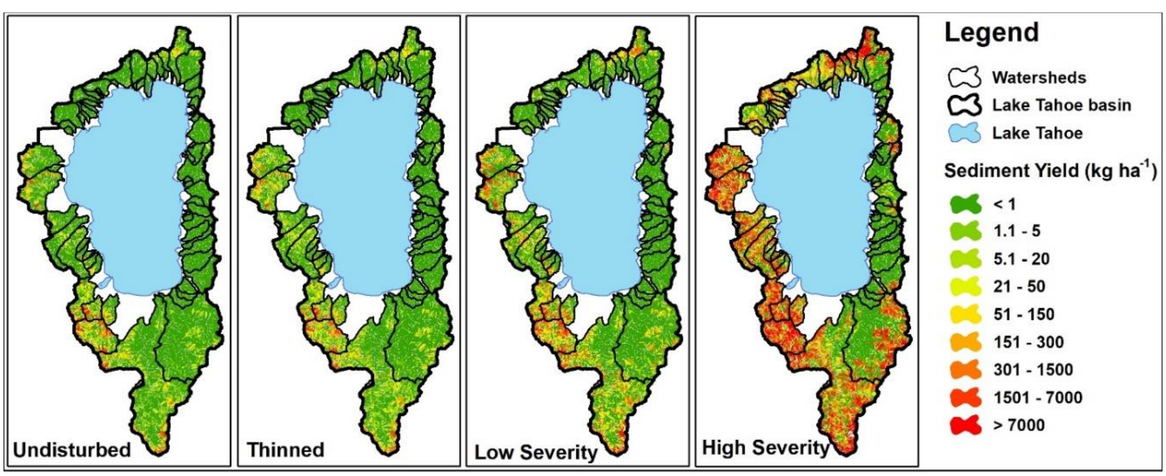

Fig. 11. Annual average sediment delivery rate for four scenarios: undisturbed, thinned, uniform low severity fire, and uniform high severity fire. Similar maps can be created from the model results for other hydrologic components (e.g. runoff, lateral flow, baseflow) or scenarios (e.g. uniform prescribed fire, uniform moderate severity fire, based on future climate scenarios, etc.).

Previous research in the basin suggested that high peak flows associated with rain-on-snow events (e.g., year 1997) can flush stored sediment from the stream channels and reduce the sediment load in the following years (Simon et al., 2004). Since forest disturbances have the potential to increase peak flows (Grant et al., 2008), we could expect rill and interrill erodibilities and the channel critical shear to change immediately post-disturbance. However, without clear guidelines from the available literature, we were unable to parameterize the WEPPcloud interface to reflect these complex changes within the channel streambed post-disturbance.

Similarly, forest treatments and wildfire have the potential to increase P concentrations in forested ecosystems mainly through increases in soil erosion and increased availability of ash (Santín et al., 2018). However, studies have found little effects from thinning (Deval et al., 2021) or from a combination of thinning and prescribed fires on P delivery (Kaye et al., 2005; Martin and Harr, 1989). Since forest wildfires, especially those that result in high soil burn severity, affect soil properties, there is more evidence that P concentrations post-wildfire increase (Lane et al., 2008; Murphy et al., 2006; Santín et al., 2018; Smith et al., 2011). However, because this information is limited in the research literature, we did not attempt to include in the model any temporal changes in phosphorus concentrations with treatment. Moreover, even if such changes were implemented, we lacked post-disturbance phosphorus observations at the modeled watersheds to validate model results.

Basin-scale statistical analyses

Management scenario comparison

Analyzing the soil erosion as an average for all the hillslopes and modeled conditions in the basin, we find that, overall, all thinning scenarios narrowly increased sediment and phosphorus yields but not as much as a moderate or high severity fire (Table 9). The annual average hillslope soil erosion from the current conditions was 107 Mg/yr while erosion from thinning varied between 110 Mg/yr for thinning (96%) and 113 Mg/yr for thinning (85%). Conversely the soil erosion for the wildfire scenarios was 298 Mg/yr, 930 Mg/yr, and 6131 Mg/yr for low, moderate, and high severity, respectively (Table 9).

The WEPP model can differentiate between soil detachment and deposition from both hillslopes and channel and can produce outputs by either hillslopes or channels or at the watershed outlets. In this study, we have mainly focused on the results from the hillslopes since they are the main target for forest management activities. However, in addition to the hillslope results, Table 9 also shows the sediment yield, total phosphorus, and sediment yield for particles <16 μm from the watershed outlets. Under current conditions, channels generate more soil erosion than hillslopes, which is expected since undisturbed forests generate minimal sediment yield (Elliot, 2004). With an increase in disturbance, though, despite an increase in sediment yield from hillslopes, total sediment transported to channels will decrease (107 Mg/yr from hillslopes vs 141 Mg/yr from channels for current conditions, compared to 6121 Mg/yr from hillslopes vs 1443 Mg/yr from channels for high severity fire) (Table 9). This shift in erosion between hillslopes and channels with an increase in disturbance is likely due to sediment deposition within the channel network.

The relatively small increase in sediment yield with thinning when compared to current conditions is likely due to the differences in land cover. Our results show that under undisturbed conditions the areas covered by grass and shrub generate substantially more erosion than the areas covered by forests (Fig. 15 in section *Treatment effects on sediment yield for slopes 30–50%*) therefore, the effects of thinning are masked by the grass and shrub areas.

Table 9. Summary of annual average sediment and phosphorus yields from hillslopes and at the watershed outlets.

Condition	Hillslopes Sediment (Mg/yr)	Outlet Sediment (Mg/yr)	Outlet Total P (kg/yr)	Outlet Sediment <16µm (Mg/yr)
Current Conditions	107	141	210	38
Thinning 85%	113	153	227	41
Thinning 93%	111	152	227	41
Thinning 96%	110	152	226	41
Prescribed Fire	183	177	255	46
Low Severity Fire	298	221	310	56
Moderate Severity Fire	930	428	559	103
High Severity Fire	6131	1443	1751	387
SimFire.fccsFuels_obs_cli	285	237	329	59
SimFire.landisFuels fut cli A2	670	474	635	110
SimFire.landisFuels obs cli	278	238	329	59

Estimating Treatment Benefits

Besides directly comparing WEPP model outputs for soil erosion from current conditions to the potential erosion from forest treatments and wildfires, we also calculated the projected change in sediment yield with thinning as an absolute difference between current conditions and thinning at 85%. The treatment benefit estimates were calculated for the Blackwood watershed as an example.

Fig. 12 shows a map of the absolute difference in soil erosion. More yellow or red areas are hillslopes where thinning will generate more erosion than current conditions. A negative value means the hillslope erosion following thinning may be less than erosion for the current condition, likely due to an earlier slower snowmelt following thinning.

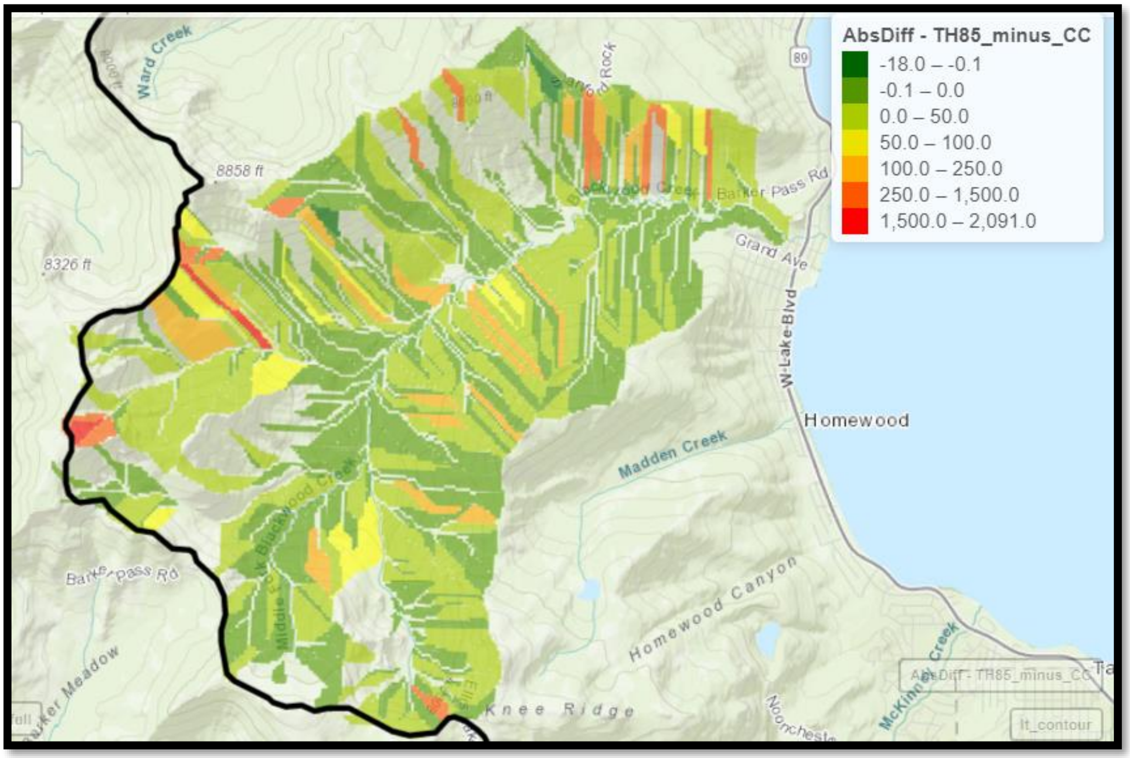

Fig. 12. Absolute sediment yield difference (kg/ha/yr)

Fig. 13 shows the treatment benefit where dark green areas represent greater benefit from thinning. For example, for the most extreme value (treatment benefit: 98,575 kg/ha) soil erosion is predicted as: Current Conditions (1,274 kg/ha), Thinning 85% (3,255 kg/ha), Low Fire (25,074 kg/ha), and Moderate Fire (129,593 kg/ha). Yellow areas are areas where the treatment benefits are non-detectable. The red areas represent hillsopes where current conditions and thinning generate zero erosion while low severity fire generates more erosion than moderate severity. The reason for the moderate severity scenario generating less sediment than low severity is likely due to faster late season snow melt rates predicted for some years beneath the denser low severity canopy compared to the moderate severity canopy. Comparing these results with the results from Fig. 12, it appears that the hillslopes that would erode more after thinning (the redder hillslopes in Fig 12) are also the hillslopes that would benefit more from thinning (greener hillslopes in Fig. 13).

We also calculated treatment benefit from thinning 1, 10, 20, 30, 40, 50, 60 times within the 60 year fire return interval as opposed to only three times. Results show that managers would need to apply thinning treatments more than 50 times within the 60 years, in order to generate erosion that would eliminate the benefits of reducing wildfire severity from moderate to low (Table 10).

Table 10. Average treatment benefit (sediment yield in kg/ha) from increasing thinning within 60 year fire return interval. Results are for the forested hillslopes of Blackwood Creek. Calculation were performed with Eq. 1.

Number of thinning operations	**1**	**3**	**10**	**20**	**30**	**40**	**50**	**60**

Average treatment benefit (kg/ha)	1663	1595	1356	1015	674	333	−8	−349

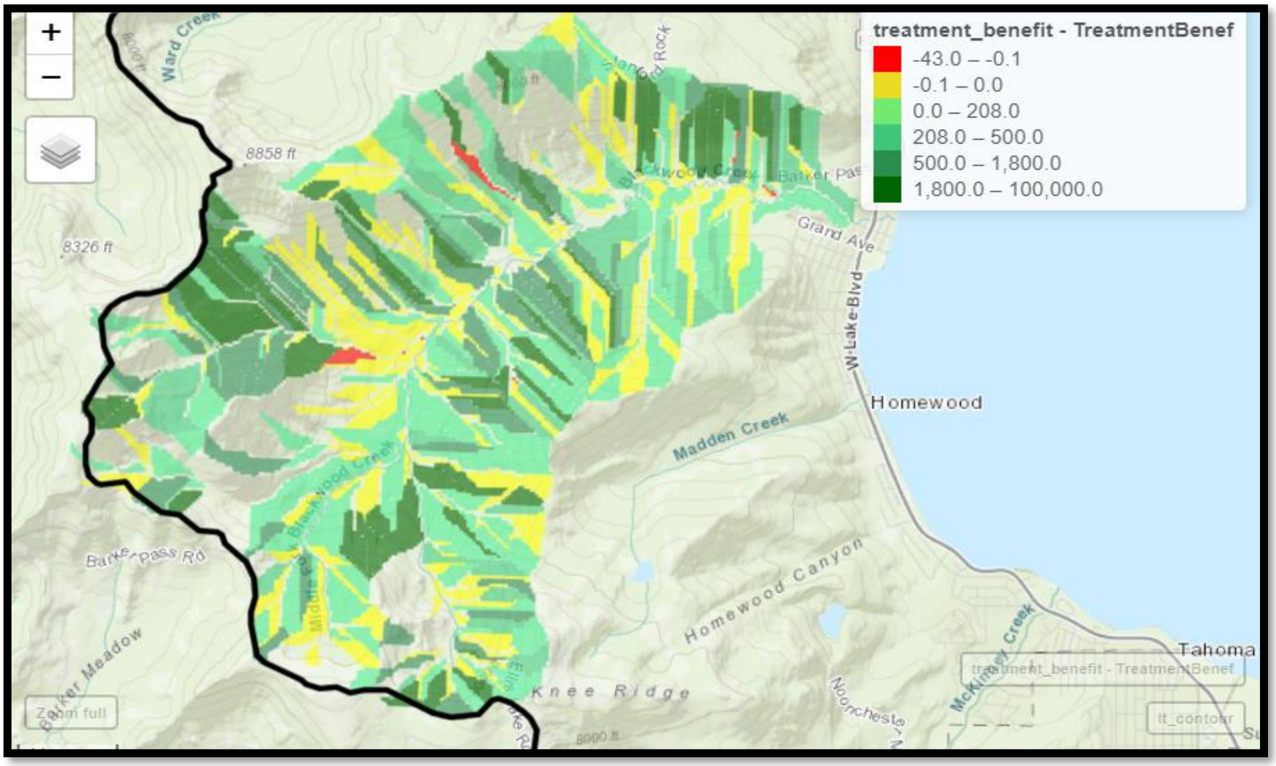

Fig. 13. Example of Treatment Benefit in Blackwood Watershed (kg/ha/yr).

As part of the overall restoration project, treatment polygons have been identified by the stakeholder group for either mechanical thinning on generally flatter slopes and hand or aerial thinning on steeper slopes. Fig. 14 shows the proposed treatment map overlaid on the treatment benefits layer.

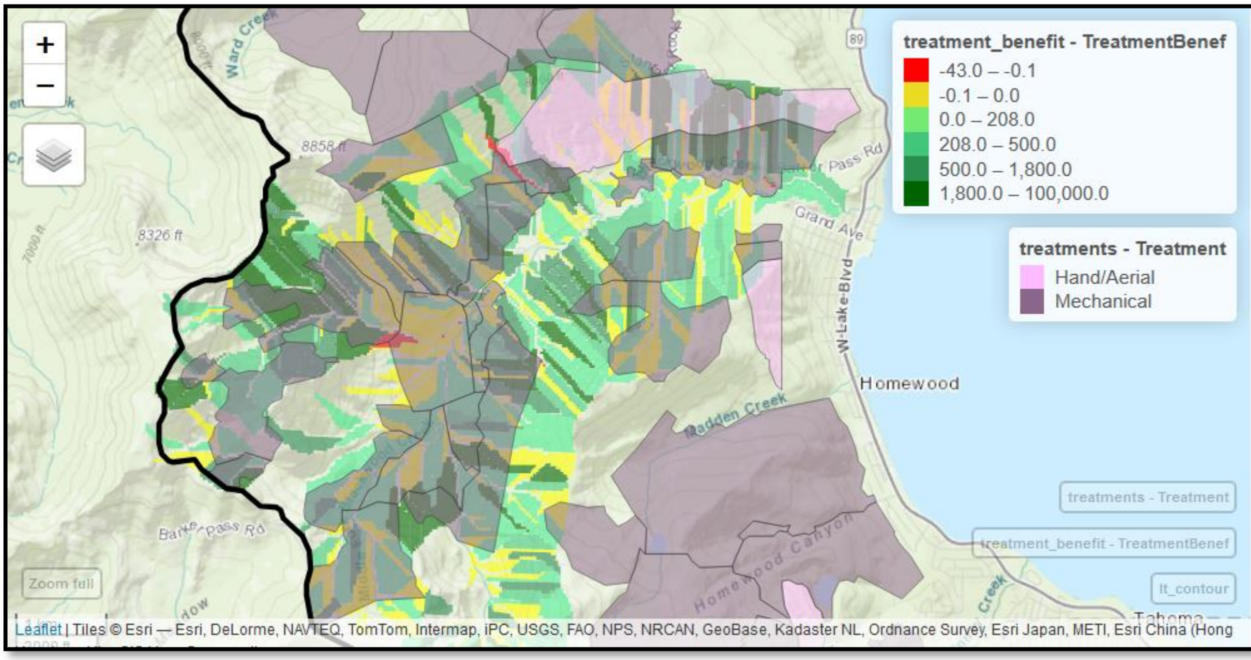

Fig. 14. Treatment benefit overlapped proposed treatment areas (kg/ha/yr).

Treatment effects on sediment yield for slopes 30–50%

We performed several data manipulations and statistical analyses to better understand the effects of slope (specifically those between 30–50%) on sediment yield.

Fig. 15 shows that on gentler slopes (<30%), the bare hillslopes will generate most of the erosion, followed by sod grasses and shrubs. On steeper slopes (>30%), most of the erosion occurred from sod grasses and shrubs. Burn conditions will increase erosion from areas covered by grass and shrubs more than from forests since these areas are generating more erosion than forested areas even under current conditions. We removed from these graphs the three runs based on the SBS predicted maps as those model runs were performed while assuming all hillslopes are forested, and, therefore cannot be compared to the runs where the management scenarios were applied by vegetation type.

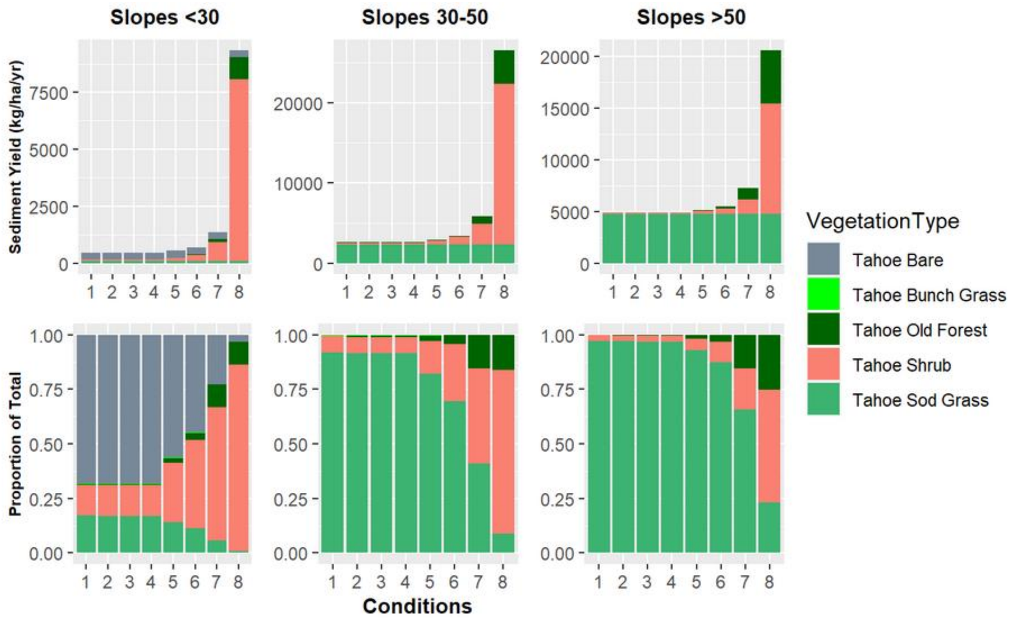

Fig. 15. Average sediment yield by vegetation type and slope categories.

Field observations following the Emerald Fire (2016) documented that that two treatment units that had been hand thinned in 2013 experienced low severity wildfire (Kyle Jacobson, Emerald Fire Report). Within those units, which were covered by slopes averaging 30–45%, there were a few areas that experienced high severity fire, which were mainly covered with shrubs. Given that the shrubs areas are generating more erosion than forests, both undisturbed and disturbed conditions, land managers should consider applying treatments on all land covers and not just on forested lands.

Managers are interested expanding thinning treatments to steeper slopes and since thinning will only occur in forested hillslopes, we also analyzed the data by slope steepness only for forested slopes. Results suggest that soil erosion will increase with slope steepness and with increase disturbance (Table 11). Slopes > 30% will generate more erosion than slopes < 30% even in undisturbed conditions (7 kg/ha/yr for slopes 30–50% as compared to 1 kg/ha/yr for slopes <30%). Thinning can increase annual average soil erosion, however less than wildfire. If we only consider the 30−50% hillslopes, thinning (85%) will increase soil erosion by 15 kg/ha/yr (22−7 kg/ha/yr) compared to current conditions. However, since the model results show that wildfire will, on average, increase soil erosion to 4226 kg/ha/yr, it would take 281 years (=4226/15) of annual thinning to reach the sediment yield from one catastrophic wildfire. If we consider the thinning scenario with the least ground disturbance (thinning 96%), it would take 469 (=4226/(16−7)) years of thinning to reach the sediment yield of a high severity wildfire (Table 11). These calculations are purely speculative since it is highly unlikely that a wildfire will burn a watershed uniformly at high severity or that the thinning treatments will be applied on all hillslopes annually, however, they provide a perspective on the difference in erosion between the thinning and the high severity scenarios.

Table 11. Average annual sediment yield (kg/ha) by slope (%) and treatment.

Scenario	<30	30-50	>50
Current Conditions	1	7	10
Thinn 96%	2	16	22
Thinn 93%	2	18	24
Thinn 85%	3	22	30
Prescr_FireF	12	73	98
Low_Severity	22	138	184
Moderate_Severity	142	894	1111
High_Severity	956	4226	5172
SimFire_LANDIS_obsClim	37	207	197
SimFire_FCCS_obsClim	40	207	232
SimFire_LANDIS_futureClim	171	801	887

If we only analyze the data for the undisturbed and 85% thinning conditions, by slope steepness, we find overall low erosion rates from thinning (Table 12). Specifically for the hillslopes between 30–50%, average sediment yield from thinning is 0.14 Mg yr^{-1}. If we further compare the average sediment yield for the 30–50% hillslopes, we find that slope length, specifically slopes >180 m have the potential to generate more erosion from thinning (2.08 Mg yr^{-1}) than slopes < 300 m (0.01 Mg yr^{-1}) (Table 13). We selected these cutoffs to reflect the maximum forest buffer (7−100 m) according to State and Federal guidelines for buffers in the U.S. (Mayer et al., 2005) and the average slope length of the hillslopes within the basin (180 m)

Table 12. Average annual sediment yield by treatment and slope steepness.

Slope steepness (%)	Current Conditions (kg ha^{-1} yr^{-1})	Thinned 85% (kg ha^{-1} yr^{-1})
<30	0.7	2.8
30–50	6.8	21.8
>50	10.4	29.9

Table 13. Average annual sediment yield by treatment and slope length for slopes between 30–50%.

Slope length (m)	Current Conditions (kg ha^{-1} yr^{-1})	Thinned 85% (kg ha^{-1} yr^{-1})
<100	0.004	0.029
100–180	0.068	0.420
>180	15.026	47.735

The odds ratio test between treatment and current conditions indicated that the odds of erosion are higher: 1.71, 1.75, 1.85, 2.59, and 4.4 for Thinn96, Thinn93, Thinn85, Prescribed Fire, and High Severity Fire, respectively. When comparing two treatments, an odds ratio of 1 means that both treatments are equal, while 2 indicates one treatment has twice the odds of occurring as the reference treatment. We found similar results for risk ratio, which calculates the risk of erosion for the entire population of each treatment condition.

The results of the ANOVA analysis were significant (*p-value* < 0.001) suggesting that soil erosion on steeper slopes does increase with treatment, however, the pairwise comparison between each treatment and the current conditions showed that only prescribed fire and high severity fires were significant and not thinning. This suggests that even the most extreme thinning technique will not greatly affect the overall soil erosion in the basin.

From both the ANOVA and the odds ratio analyses we can conclude that thinning will increase the risk of erosion, but when thinned hillslopes erode, the sediment yield is no different from an untreated hillslope (roughly 8 kg ha^{-1}).

Variable importance

The next analyses are based on a series of variables created from the model input files. These include sediment yield (kg $ha^{-1}yr^{-1}$), and various variables related to hillslope physical attributes, topography, and soils (Table 14).

Correlations

Results for all variables and watersheds suggest that for current condition model results sediment yield is positively correlated with hillslope length (*p-value* = 0.39), precipitation (*p-value* = 0.23), hillslope area (*p-value* = 0.22), and percent slope (*p-value* = 0.19) (Table 15). These results suggest that soil erosion increases on longer and larger hillslopes and on those that receive more precipitation. For the disturbed conditions, we found similar correlations, however, they increase with condition in the following order: thinning, prescribed fire, high severity fire (Table 15). Some variables were negatively correlated with sediment yield: plant available water (*p-value* = −0.20), slope width (*p-value* = −0.20), and total soil saturation amount (*p-value* = −0.21). While these correlations are not strong, they suggest that soil erosion increases with a decrease in soil moisture. The negative correlation with slope width implies that soil erosion is greater on narrower slopes. This is perhaps because narrower slopes tend to also be found on steeper slopes at high elevation, and therefore have a greater risk of erosion.

Table 14. List of variables used in the variable importance data analyses.

Variable	**Description**
Sediment_kg_ha	Sediment Yield in (kg/ha)
precip_mm	Precipitation (mm)
length_m	Slope Length (m)
width	Slope Width (m)
area_ha	Area (ha)
aspect	Aspect (degrees)
slope	Slope (%)
TEXT	Texture (Volcanic/Granitic/Alluvial)
LNDUS	Landuse
albedo	Albedo (0-1)
ani	Anisotropy (-)
bd	Bulk Density (kg/m3)
bed_ksat	Hydraulic conductivity of the underlying geology (mm/hr)
kinter	Interrill erodibility (kg s/m-4)
cec	Cation Exchange Capacity (meq/100g)
clay	Clay (%)
fc	Field Capacity (m3/m3)
fc_rc	Field Capacity corrected for rock content (m3/m3)
horizons	No of soil horizons
krill	Rill erodibility (s/m)
ksat	Saturated hydraulic condictivity (mm/hr)
mukey	Soil name/key from SSURGO
om	Organic matter (%)
plant_available_water_mm	Plant available water (mm)
rocks	Rocks (%)
sand	Sand (%)
sat_wat_conc_rc	Saturated water content (m3/m3)
tauc	Critical Shear (Pa)
total_depth	Total soil depth (mm)
total_sat_amt_mm	Total saturation ammount (mm)
wp	Wilting Point (m3/m3)
wp_rc	Wilting point corrected for rock content (m3/m3)
Elev	Elevation (m)

Table 15. Spearman correlations (*p-values*) of sediment yield with all variables based on the model results from all watersheds. See Table 14 for variable names.

Variables	Current Conditions	Thinning 85%	Prescribed Fire	High Severity Fire
length_m	0.39	0.48	0.51	0.59
precip_mm	0.23	0.32	0.33	0.41
area_ha	0.22	0.28	0.32	0.40
slope	0.19	0.21	0.22	0.18
anis	0.18	0.22	0.13	0.11
Elev	0.13	0.17	0.14	0.17
ksat	0.12	0.13	0.03	−0.03
bd	0.10	0.09	−0.02	−0.07
rocks	0.08	0.09	0.18	0.23
wp	0.06	0.11	0.16	0.23
om	0.05	0.09	0.09	0.12
clay	0.05	0.07	0.16	0.25
cec	0.03	0.06	0.16	0.26
sand	0.02	0.00	−0.10	−0.20
wp_rc	−0.01	0.00	−0.01	−0.01
aspect	−0.03	−0.04	−0.07	−0.10
albedo	−0.05	−0.07	−0.04	−0.02
fc	−0.08	−0.05	−0.01	0.02
fc_rc	−0.10	−0.10	−0.14	−0.16
sat_wat_conc_rc	−0.13	−0.15	−0.20	−0.23
bed_ksat	−0.14	−0.19	−0.16	−0.23
total_depth	−0.15	−0.19	−0.12	−0.12
horizons	−0.16	−0.18	−0.08	−0.02
plant_available_water_mm	−0.20	−0.23	−0.21	−0.24
width	−0.20	−0.23	−0.20	−0.20
total_sat_amt_mm	−0.21	−0.25	−0.22	−0.26

When considering the data by individual watersheds, the correlations between sediment yield and slope length are much stronger for Blackwood, Ward, and Upper Truckee Watersheds (e.g. for Blackwood the *p-value* = 0.64, 0.79, 0.80, and 0.88 for Current Conditions, Thinning, Prescribed Fire, and High Severity fire, respectively). Interestingly, the correlations with precipitation were much weaker when considering the data by watershed, which suggests that precipitation is more important regionally (west/east) rather than locally (within watershed). Slope area, percent slope, and elevation were also strongly correlated with sediment yield for all watersheds, however, for Trout, bulk density (*p-value* = 0.35), and anisotropy (*p-value* = 0.35), were slightly more correlated with sediment yield than slope length (*p-value* = 0.31) (Tables 16−19).

The positive correlation between sediment yield and hillslope area could be indirectly because of the correlation between slope length and hillslope area (*p-value* = 0.71; data not shown). Similarly, sediment yield increases with elevation, which could also be because slope steepness increases with elevation (*p-value* = 0.38; data not shown) and also because higher elevation areas, especially in watersheds like Blackwood and Ward, are characterized by sparser vegetation and rock outcrops, which generate more erosion.

Soil bulk density is calculated as the dry weight of soil divided by its volume and it increases with compaction and depth. Our results show that soil erosion increases with bulk density for the Trout watershed (Table 18). This is likely due to the fact that soils with high bulk densities also tend to have more sands, less organic matter, and less available water capacity. Soil anisotropy is a term used to denote preferential flow direction in soils and depends on the structure of the soil. Soil anisotropy ratio signifies a prevalence of lateral versus vertical hydraulic conductivity. In soils with higher anisotropy values, water movement through the soil profile is higher laterally than vertically, and is higher in steeper slopes (Zaslavsky and Rogowski, 1969). In WEPP, a value of 10 (unitless) is assigned for the first 400 mm of soil depth and 1 (unitless) for the remaining soil depth. The positive correlation between anisotropy and erosion suggests that soil erosion increases on slopes with greater lateral flow, and therefore on steeper slopes.

Table 16. Spearman correlations (*p-values*) of sediment yield with all variables based on the model results for the Blackwood Creek watershed. See Table 14 for variable names.

Variables	Current Conditions	Thinning 85%	Prescribed Fire	High Severity Fire
length_m	0.64	0.79	0.80	0.88
area_ha	0.43	0.54	0.60	0.69
slope	0.29	0.37	0.39	0.39
Elev	0.23	0.25	0.25	0.33
albedo	0.15	0.11	0.10	0.08
anis	0.15	0.13	0.12	0.13
wp	0.13	0.13	0.16	0.09
precip_mm	0.07	0.05	0.07	0.12
bd	0.06	0.08	0.09	0.03
clay	0.05	0.05	0.05	0.02
fc	0.04	0.04	0.10	0.02
rocks	0.03	0.00	−0.05	0.05
cec	0.02	0.00	−0.04	0.06
wp_rc	0.01	0.03	0.07	−0.02
om	0.00	0.00	−0.02	0.04
horizons	−0.02	−0.03	−0.01	−0.01
ksat	−0.02	−0.01	−0.07	0.01
fc_rc	−0.02	−0.01	0.04	−0.05
aspect	−0.05	0.04	0.07	0.06
sand	−0.06	−0.04	0.01	−0.06
plant_available_water_mm	−0.07	−0.05	−0.01	−0.09
total_sat_amt_mm	−0.08	−0.07	−0.02	−0.11
total_depth	−0.08	−0.07	−0.03	−0.12
sat_wat_conc_rc	−0.08	−0.06	−0.01	−0.09
bed_ksat	−0.18	−0.13	−0.13	−0.13
width	−0.31	−0.34	−0.28	−0.27

Table 17. Spearman correlations (*p-values*) of sediment yield with all variables based on the model results for the Ward Creek watershed. See Table 14 for variable names.

Variables	Current Conditions	Thinning 85%	Prescribed Fire	High Severity Fire
length_m	0.60	0.73	0.76	0.86
area_ha	0.37	0.50	0.53	0.67
slope	0.25	0.35	0.40	0.44
Elev	0.22	0.24	0.19	0.33
albedo	0.17	0.22	0.27	0.25
clay	0.17	0.09	0.05	−0.04
anis	0.16	0.20	0.24	0.22
precip_mm	0.14	0.11	0.06	0.11
rocks	0.13	0.18	0.18	0.24
ksat	0.11	0.12	0.09	0.11
bd	0.10	0.00	−0.05	−0.16
cec	0.10	0.18	0.17	0.27
wp	0.06	0.00	−0.01	−0.12
aspect	−0.02	−0.02	−0.01	0.02
om	−0.09	0.00	0.02	0.11
wp_rc	−0.09	−0.14	−0.15	−0.22
sand	−0.12	−0.07	0.00	−0.01
fc	−0.12	−0.15	−0.13	−0.20
fc_rc	−0.13	−0.18	−0.17	−0.23
plant_available_water_mm	−0.16	−0.20	−0.20	−0.23
total_depth	−0.20	−0.24	−0.23	−0.26
total_sat_amt_mm	−0.20	−0.24	−0.23	−0.27
horizons	−0.21	−0.10	−0.04	0.04
sat_wat_conc_rc	−0.21	−0.25	−0.24	−0.27
bed_ksat	−0.25	−0.22	−0.19	−0.13
width	−0.34	−0.33	−0.33	−0.27

Table 18. Spearman correlations (*p-values*) of sediment yield with all variables based on the model results for the Trout Creek watershed. See Table 14 for variable names.

Variables	Current Conditions	Thinning 85%	Prescribed Fire	High Severity Fire
bd	0.35	0.41	0.41	0.43
anis	0.35	0.38	0.38	0.36
length_m	0.31	0.40	0.41	0.53
sand	0.30	0.30	0.28	0.20
Elev	0.26	0.32	0.31	0.40
slope	0.24	0.29	0.29	0.33
wp	0.21	0.19	0.21	0.17
wp_rc	0.20	0.17	0.17	0.09
area_ha	0.19	0.22	0.24	0.31
precip_mm	0.16	0.21	0.21	0.21
ksat	0.06	0.09	0.08	0.14
rocks	0.00	0.05	0.05	0.14
clay	−0.01	0.01	0.02	0.08
cec	−0.01	0.02	0.02	0.09
fc_rc	−0.03	−0.08	−0.08	−0.17
aspect	−0.04	−0.05	−0.06	−0.03
om	−0.06	−0.09	−0.09	−0.09
width	−0.14	−0.19	−0.19	−0.25
sat_wat_conc_rc	−0.14	−0.20	−0.20	−0.29
fc	−0.17	−0.20	−0.18	−0.20
bed_ksat	−0.17	−0.19	−0.20	−0.22
albedo	−0.28	−0.27	−0.26	−0.19
horizons	−0.32	−0.32	−0.32	−0.28
plant_available_water_mm	−0.32	−0.37	−0.36	−0.39
total_sat_amt_mm	−0.34	−0.40	−0.39	−0.43
total_depth	−0.35	−0.37	−0.37	−0.37

Table 19. Spearman correlations (*p-values*) of sediment yield with all variables based on the model results for the Upper Truckee Watershed. See Table 14 for variable names.

Variables	Current Conditions	Thinning 85%	Prescribed Fire	High Severity Fire
length_m	0.54	0.66	0.67	0.73
area_ha	0.36	0.47	0.49	0.55
slope	0.32	0.35	0.37	0.32
Elev	0.21	0.29	0.29	0.33
bd	0.10	0.08	0.06	0.07
anis	0.08	0.15	0.15	0.17
clay	0.08	0.06	0.06	0.07
rocks	0.07	0.05	0.04	0.02
precip_mm	0.07	0.16	0.18	0.22
ksat	0.06	0.04	0.03	0.00
wp	0.04	0.07	0.09	0.14
cec	0.03	0.03	0.03	0.04
wp_rc	−0.02	0.01	0.03	0.07
albedo	−0.02	−0.06	−0.07	−0.11
fc	−0.03	0.00	0.02	0.07
bed_ksat	−0.03	−0.06	−0.07	−0.08
sand	−0.04	−0.02	−0.02	−0.03
aspect	−0.04	−0.05	−0.05	−0.05
om	−0.07	−0.03	−0.02	0.00
total_depth	−0.07	−0.13	−0.13	−0.17
fc_rc	−0.08	−0.05	−0.03	0.01
horizons	−0.09	−0.13	−0.14	−0.15
plant_available_water_mm	−0.09	−0.12	−0.12	−0.12
total_sat_amt_mm	−0.12	−0.16	−0.16	−0.18
sat_wat_conc_rc	−0.12	−0.11	−0.10	−0.08
width	−0.25	−0.25	−0.24	−0.22

PCA

The PCA analysis revealed similar relationships between variables for all management condition. For comparison we are only presenting the results for current conditions and high severity fire (Figs. 16 and 17). The first two components of PCA, cumulatively, explained 41% of variance for all management conditions. The data seems to be spread uniformly along the two principal components, however, data groups in small clusters, which is likely due to differences among individual watersheds. Additionally, higher sediment yield values are mainly found on the negative values for component 1 and positive values for component 2, while lower sediment yield values are mainly found on the positive values for component 1 and negative values for component 2. This pattern is more apparent for the results based on the high severity management scenario. While the loading of the sediment yield variable does not have a significant weight on the two principal components compared to other variables, it is in the same direction as slope length, slope area, slope width, % rocks, % organic matter, precipitation, and albedo, which signifies positive correlations with these variables. From the PCA analysis we cannot draw clear conclusions regarding sediment yield and slope, however, the analysis helps us better understand the relationships between the data.

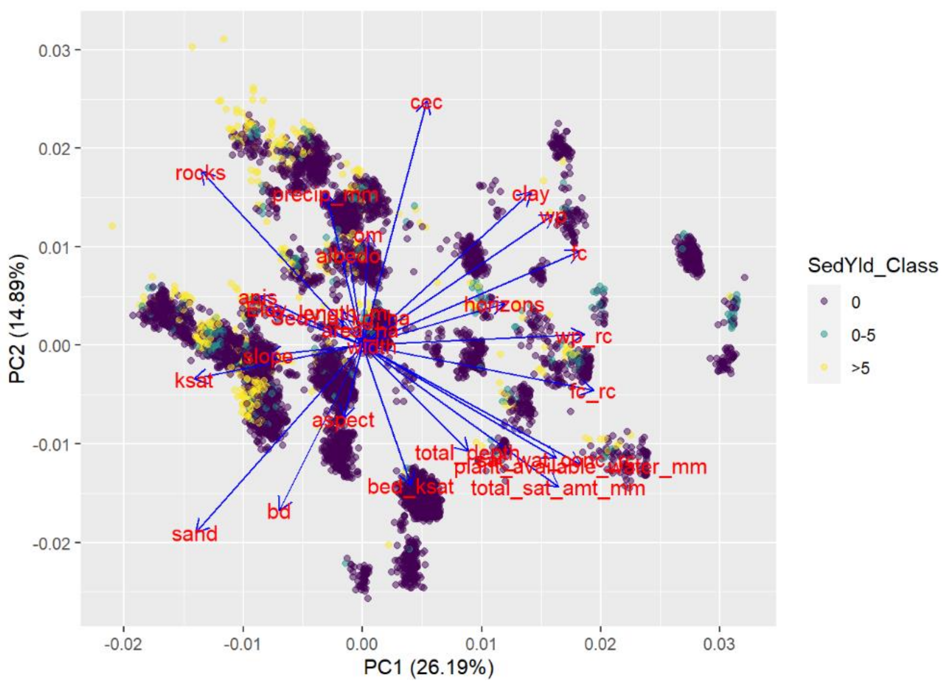

Fig. 16. Results of the principle component analysis for the 27 environmental variables based on all forested hillslope for current conditions. The colors represent sediment yield classes. Description of variable abbreviations can be found in Table 14.

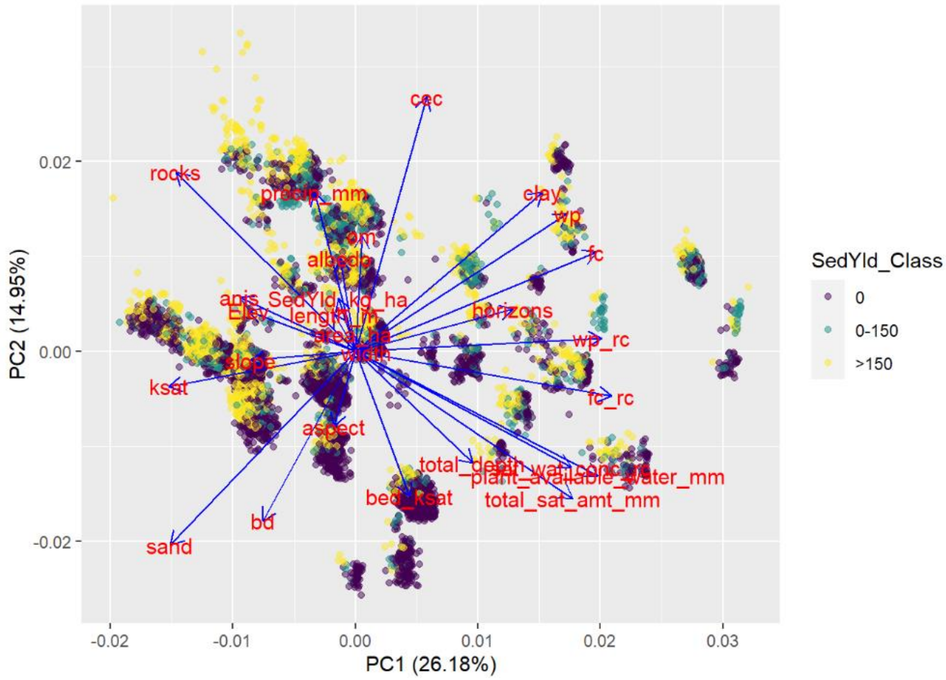

Fig. 17. Results of the principle component analysis for the 27 environmental variables based on all forested hillslope for high severity fire. The colors represent sediment yield classes. Description of variable abbreviations can be found in Table 14.

RF

We first applied the random forest model to predict weather a hillsope will erode or not. Under current conditions, approximately 10% of the hillslopes across the Lake Tahoe Basin erode, while under high severity fire, the percentage increases to slightly over 40% (Fig. 18, left column). These results suggest, at least according to the WEPP model, that approximately 60% of the hillslopes will not erode even under high severity fire, which is the most extreme modeled scenario. The non-eroding hillslopes are mainly found in the eastern-side of Lake Tahoe (Fig. 11), however, all watersheds, including the highly eroding ones such as Blackwood and Upper Truckee also have non-eroding hillslopes.

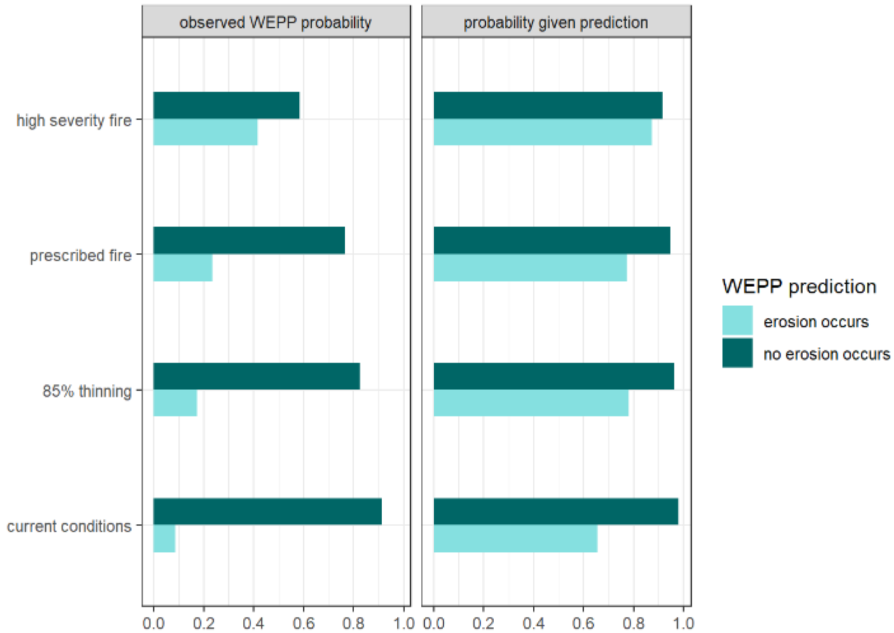

Fig. 18. Accuracy of the random forest prediction of eroding vs. non-eroding hillslopes by management scenario.

To better understand the differences between the hillslopes that erode and those that do not erode, we calculated the average values for several environmental variables by hillslopes that erode and those that do not erode. Table 20 shows that hillslopes that do not erode, have on average shorter hillslopes lengths, receive less precipitation, have smaller areas and wider widths, and are mainly facing SSW slopes. Both elevation and slope were similar for hillslopes from the two erosion categories.

Table 20. Averages of sediment yield and environmental variables by hilllsopes that erode vs. those that do not erode.

SedVar	Sediment Yield (kg/ha)	Slope Length (m)	Slope Steepness (%)	Precipitation (mm)	Elevation (m)	Area (ha)	Width (m)	Aspect (degrees)	Soil Depth (mm)
NoErod	0	114	0.24	917	2228	3.63	349	206	1223
Erod	5190	272	0.27	1119	2281	6.06	298	180	1152

Plotting the variable importance from the random forest model, we find that the most important variables for predicting areas that erode are: slope length, followed by precipitation, %slope, slope area, slope width, and elevation (Fig. 19). While slope length and precipitation are at the top for each of the four management scenarios compared in this analysis, the order of the other variables varies with scenario (Fig. 19).

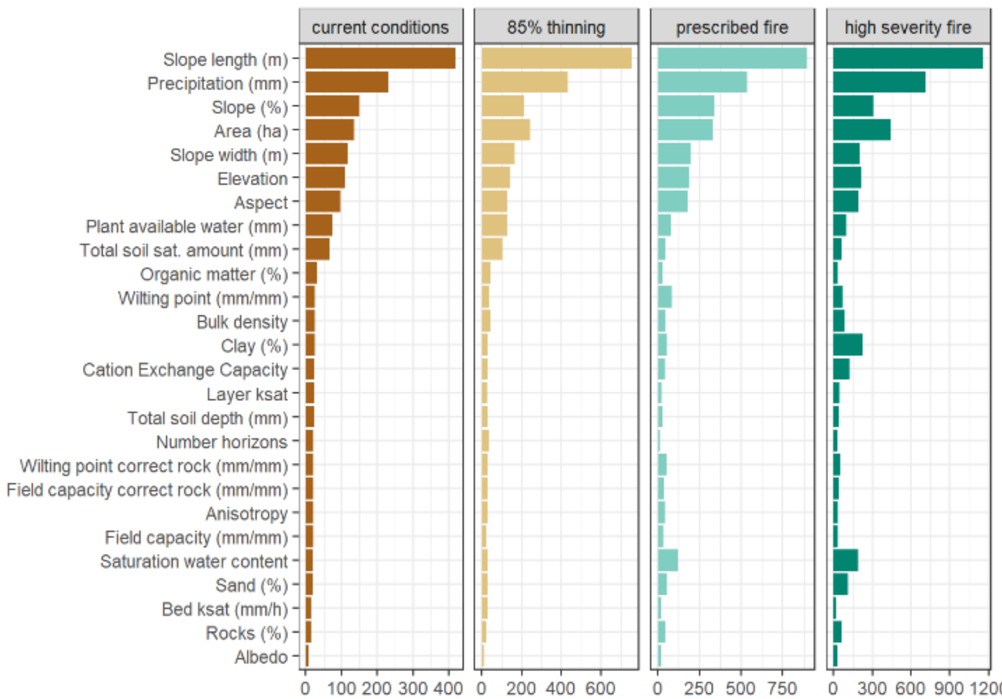

Fig. 19. Variable importance for the RF model (testing eroding vs. non-eroding hillslopes) by management scenario.

We then applied the RF model to predict actual values of sediment yield. The RF model accurately predicted soil erosion for all four management conditions (Fig. 20). Plotting the % increase in Mean Squared Error (MSE) we find that, similar to the previous analysis, the most important variables for predicting sediment yield are length, followed by %slope and precipitation (Fig. 21).

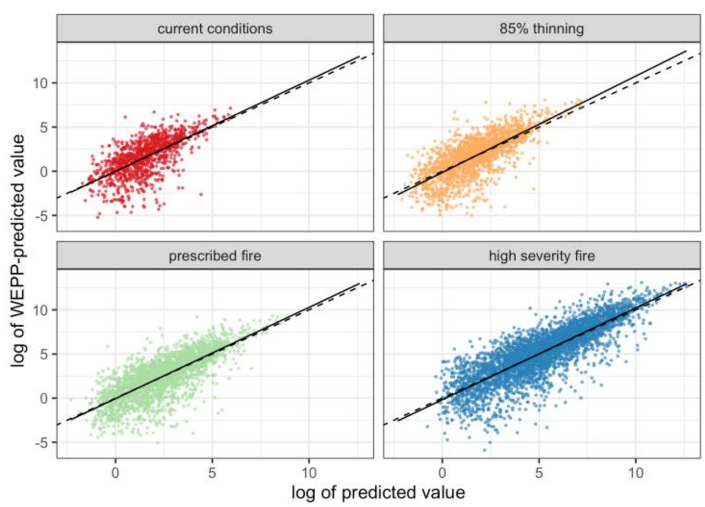

Fig. 20. WEPP-predicted vs RF predicted sediment yield based on several environmental variables.

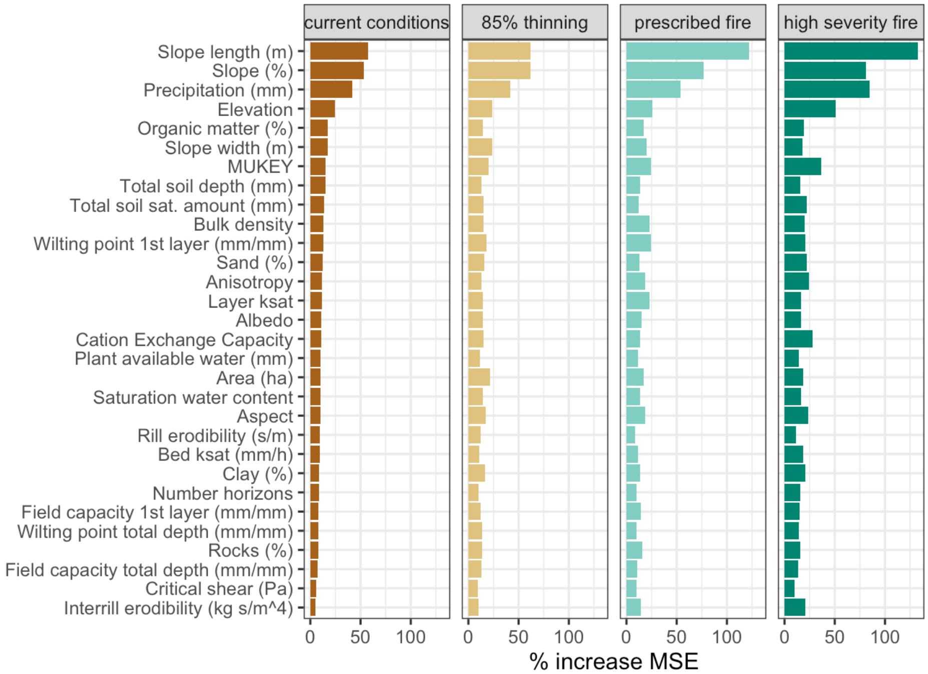

Fig. 21. Percent increase in mean squared error (MSE) by modeled variables and scenarios.

Additional graphs and data summaries

Fig. 22 shows the top ten watersheds within the Lake Tahoe Basin with the greatest sediment delivery from hillslopes for the undisturbed conditions. These calculations are performed by selecting only the forested hillslopes.

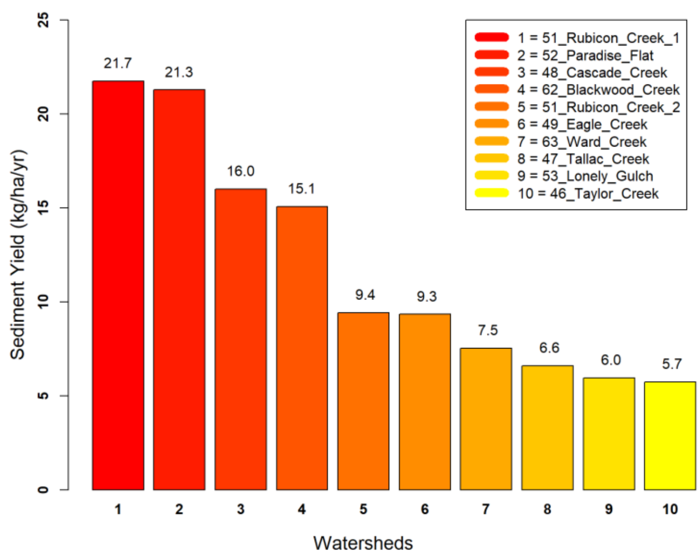

Fig. 22. Ten watersheds with the greatest sediment delivery from hillslopes to channels for the undisturbed forest conditions.

The order of the watersheds changes when accounting for the watershed area (Fig. 23). Blackwood, Upper Truckee, and Ward are the greatest contributors.

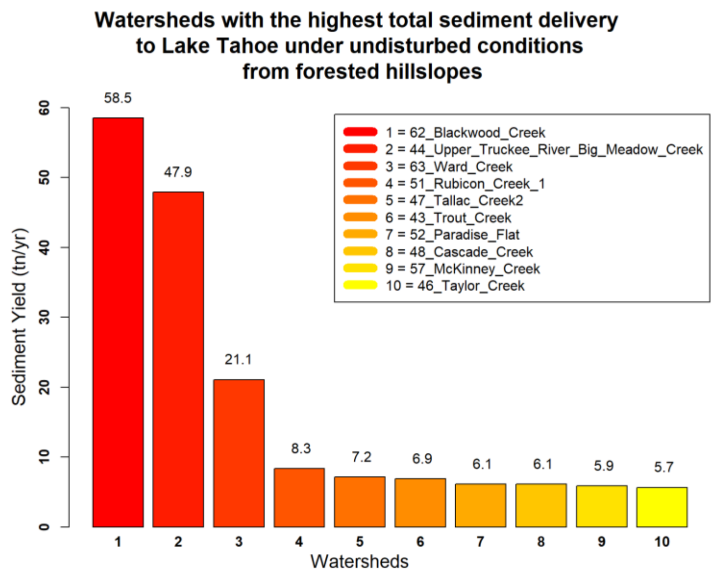

Fig. 23. Top ten watersheds delivering sediment to Lake Tahoe.

Soil erosion and sediment delivery are influenced by topography, land cover, soil properties and climate. Based on the hillslope output data we created additional tables to quantify the effects of each of these individual factors on soil erosion. All calculations are based on the model results from the current condition scenario. Variable precipitation, was split based on the average precipitation at all the hillslopes within the basin (1000 mm). Tables 20−24 show the average sediment yield by various variables. From these tables we can conclude:

- Volcanic soils erode more than granitic and alluvial soils (Table 21);
- Sediment yield is greatest on hillslope that receive more than 1000 mm of precipitation and have slopes > 50%; The least sediment yield is found on hillslopes with less than 1000 mm precipitation and slope steepness < 30% (Table 22);
- Hillslopes between 2600−2800 m generate more erosion than hillslopes found at both lower and higher elevation (Table 23);
- Soil erosion is greater on soils with more rock outcrops (e.g. Melody and Ellispeak) (Table 24);

- Soil erosion is similar on all aspects, except on western slopes, where soil loss is less than half of the soil loss predicted on south-, north-, and east-facing slopes (Table 25).

Table 21. Average sediment yield (kg/ha) by texture and condition.

Texture	Current Conditions	Thinning 85%	Prescribed Fire	High Severity Fire
Alluvial	1.64	4.05	22	519
Granitic	2.22	5.48	21	1278
Volcanic	6.03	23.42	77	5431

Table 22. Average sediment yield by slope steepness and precipitation.

Precipitation Category	Slope Steepness	Sediment yield (kg/ha)	Sediment yield (tonnes)
<1000mm	<30	0.08	0.0005
>1000mm	<30	1.38	0.0087
<1000mm	>50	3.31	0.0272
>1000mm	>50	16.93	0.1157
<1000mm	30−50	0.63	0.0045
>1000mm	30−50	13.70	0.0911

Table 23. Average soil loss by elevation (m).

Elevation Category	Sediment yield (kg/ha)	Sediment yield (tonnes)
<1800	0.0	0.00
1800−2000	0.36	0.00
2000−2200	1.70	0.01
2200−2400	3.26	0.02
2400−2600	5.33	0.03
2600−2800	8.98	0.05
2800−3000	3.89	0.03
>3000	0.05	0.00

Table 24. Average soil loss by top ten eroding soils.

Soil Name	Sediment yield (kg/ha)
Melody-Rock outcrop complex	83
Lithnip-Meiss-Hawkinspeak association	59

Ellispeak-Rock outcrop complex	44
Rubble land-Glenalpine complex	33
Meeks extremely stony loamy coarse sand	26
Ellispeak-Waca complex	21
Waterpeak-Rock outcrop complex	19
Temo-Witefels complex	16
Tinker-Rock outcrop	11
Mountrose-Wardcreek-Melody complex	10

Table 25. Average soil loss by aspect.

Aspect	Sediment yield (kg/ha)	Sediment yield (tonnes)
E	3.99	0.02
N	3.75	0.02
S	3.93	0.03
W	1.45	0.01

V. CONCLUSIONS

In the current study, we demonstrated that the WEPPcloud interface can successfully simulate general trends in streamflow, sediment, and phosphorus in watersheds with different physiographic settings with minimal calibration. Additionally, we demonstrated the applicability of the interface to various forest fuel treatments and wildfire scenarios, which can provide land and water resources managers with site-specific information of the spot areas in their watersheds to control soil erosion and phosphorus transport with forest management practices. The minimal calibration performed in this study involved manual alterations of calibrating parameters that are not easily found in national databases (i.e., kb, Ksub, τc, P concentrations). However, previous research, and the current study, demonstrate that at least some of these parameters could be inferred from geology (kb) or could be determined from observed data at nearby watersheds (kb, τc, P concentrations).

The results from the treatment benefit calculations for Blackwood, revealed the sensitive areas within the watershed that are more prone to erosion. The results suggest that hillslopes that are more prone to erosion post-thinning would also benefit more from thinning by avoiding high erosion rates from a potential wildfire.

Land managers were interested to determine if thinning would increase sediment yield on steeper slopes (30−50%). To address this question we performed several data summaries and statistical analyses, which showed that when we analyze the data considering all vegetation types, most sediment yield on slopes between 30−50% comes from areas covered by shrubs and grasses and not from forested areas, which suggests that land managers should consider applying treatments on all land covers and not just on forested lands.

The results from the ANOVA and the odds ratio analyses on hillslopes between 30 and 50% showed that thinning will increase the risk of erosion, but when thinned hillslopes erode, the sediment yield is no different when compared to an untreated hillslope. When we further plotted the data by slope length we found that longer hillslopes generate significantly more sediment yield than shorter slopes. Additional data analyses revealed other variables that are influencing soil erosion in the basin, however, slope length was consistently identified as a major driver. Therefore managers should consider thinning activities that either include buffers or add natural breaks along the slopes (i.e. thin only portions of a slope).

Mechanical thinning has the potential to generate more erosion through soil disturbances related to rutting, however, current management practices are likely to address this risk by using slash mats (harvest residue on which harvesting machinery can move) or other methods to minimize soil disturbance and increase ground cover. Newer mechanized equipment (with flexible tracks or frames, or with tethering), which were designed to be operated on steep terrains, can further minimize soil disturbance. Similarly, newer harvesting machines are equipped with larger inflatable wheels and they can also carry instead of dragging logs from site-to-site, which reduce compaction and minimize disturbance.

This modeling study showed that thinning minimally increased soil erosion when compared to the results from the wildfire. A large body of research suggests that forest treatments will help decrease risks of wildfire, with important social benefits.

Other mitigation strategies to minimize impacts of treatments on sediment and water quality include:

- Encouraging high patchiness of treatments.
- Staggering treatments in time and space to minimize cumulative impacts at the watershed outlet.
- Designing topographically-based buffers to reduce the connectivity of potential source areas to stream networks. These buffers could be strips of undisturbed soils on long slopes and at the bottom of steep slopes. This approach would be distinct from standard stream zone buffers, as full restoration goals may include thinning and burning within riparian areas.
- Planning upland treatments to follow meadow restoration projects that are designed to help capture eroded sediments and burned debris on floodplains. Such effects have been suggested for meadow restoration projects to mitigate channel incision, such as at Trout Creek.
- Using care when reopening roads to access areas for thinning to minimize erosion risk.

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APPENDIX

Interpolated values of baseflow, deep seepage, channel critical shear, and phosphorus.

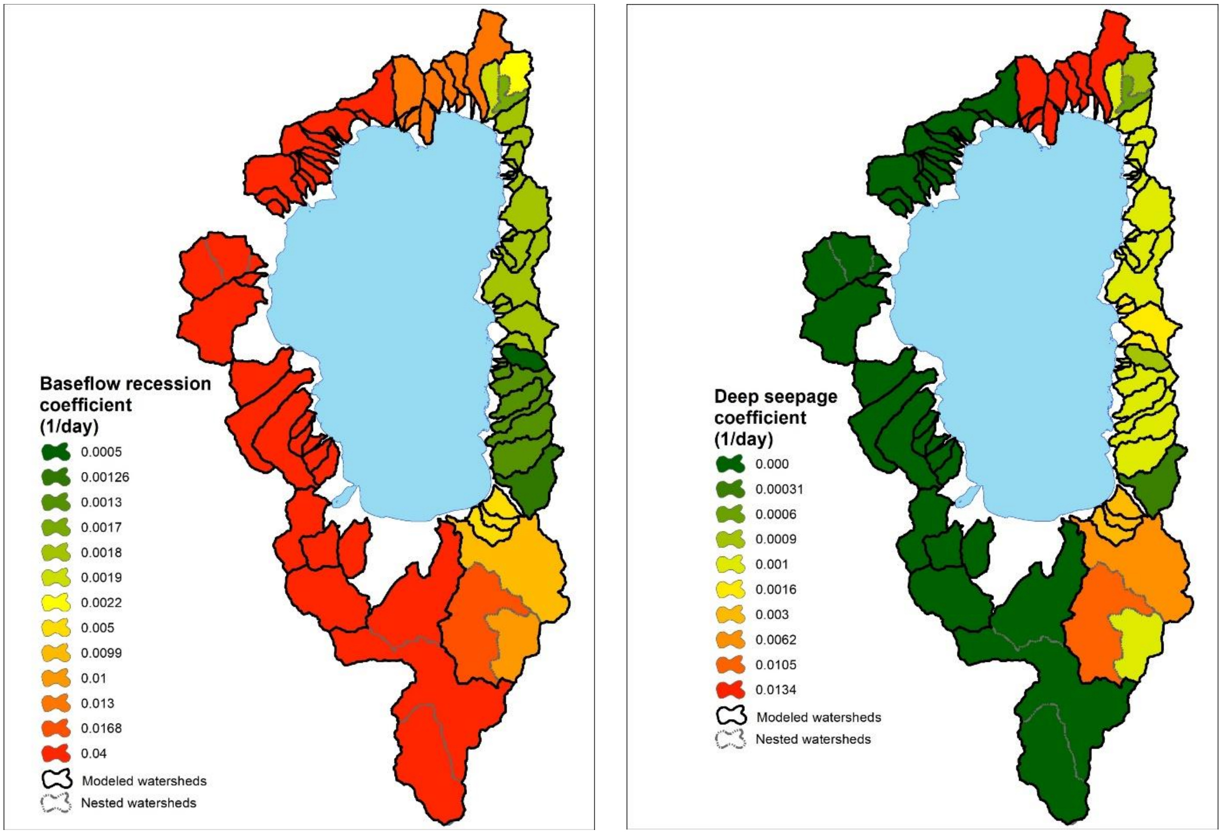


Figure A1. Interpolated estimated values of baseflow and deep seepage recession coefficients for Lake Tahoe basin watersheds in California/ Nevada.

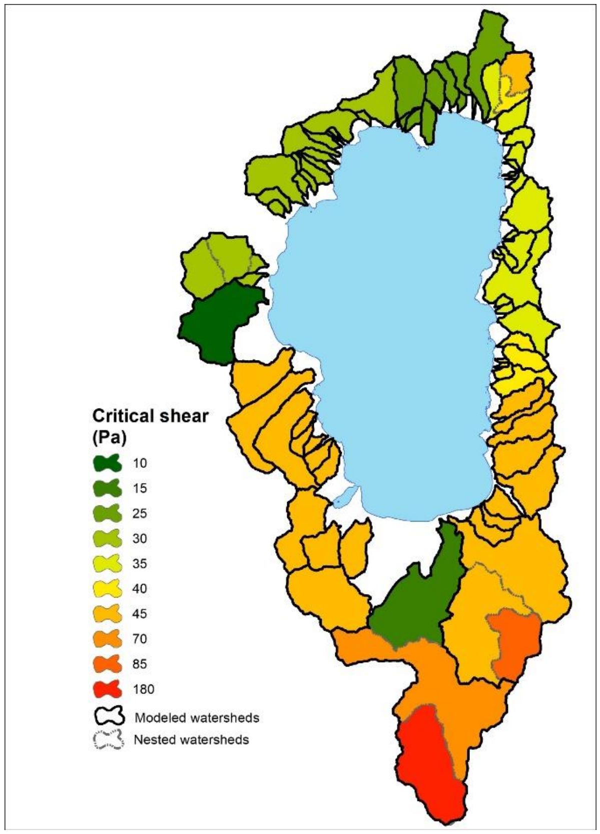
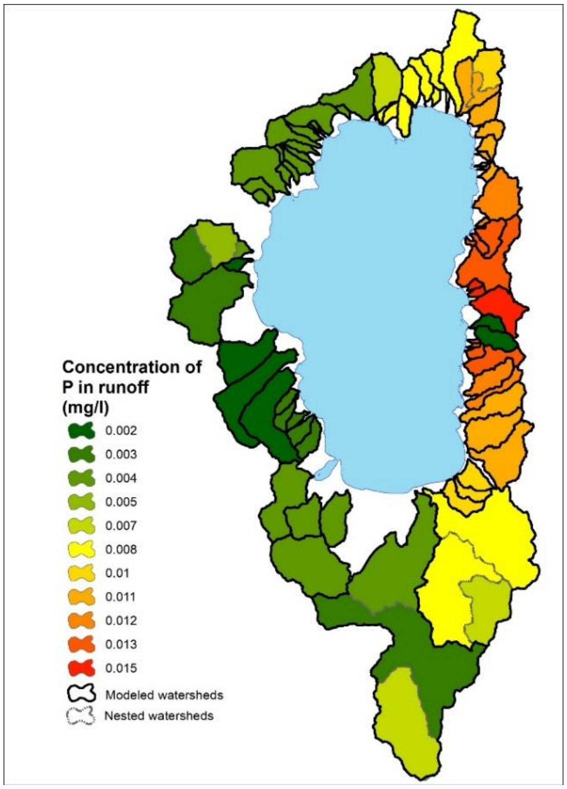
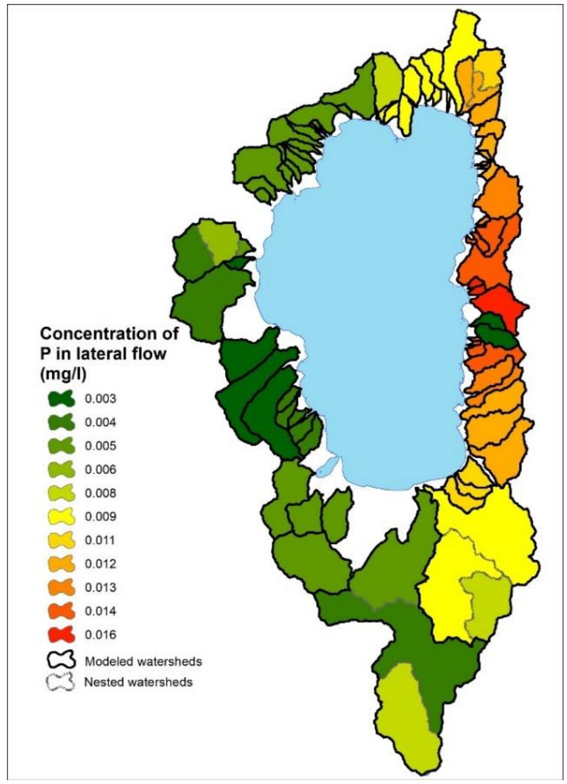


Figure A2. Interpolated channel critical shear for Lake Tahoe basin watersheds in California/ Nevada.


Concentration of
P in runoff
(mg/l)
0.002
0.003
0.004
0.005
0.007
0.008
0.01
0.011
0.012
0.013
0.015
Modeled watersheds
Nested watersheds


Concentration of
P in lateral flow
(mg/l)
0.003
0.004
0.005
0.006
0.008
0.009
0.011
0.012
0.013
0.014
0.016
Modeled watersheds
Nested watersheds

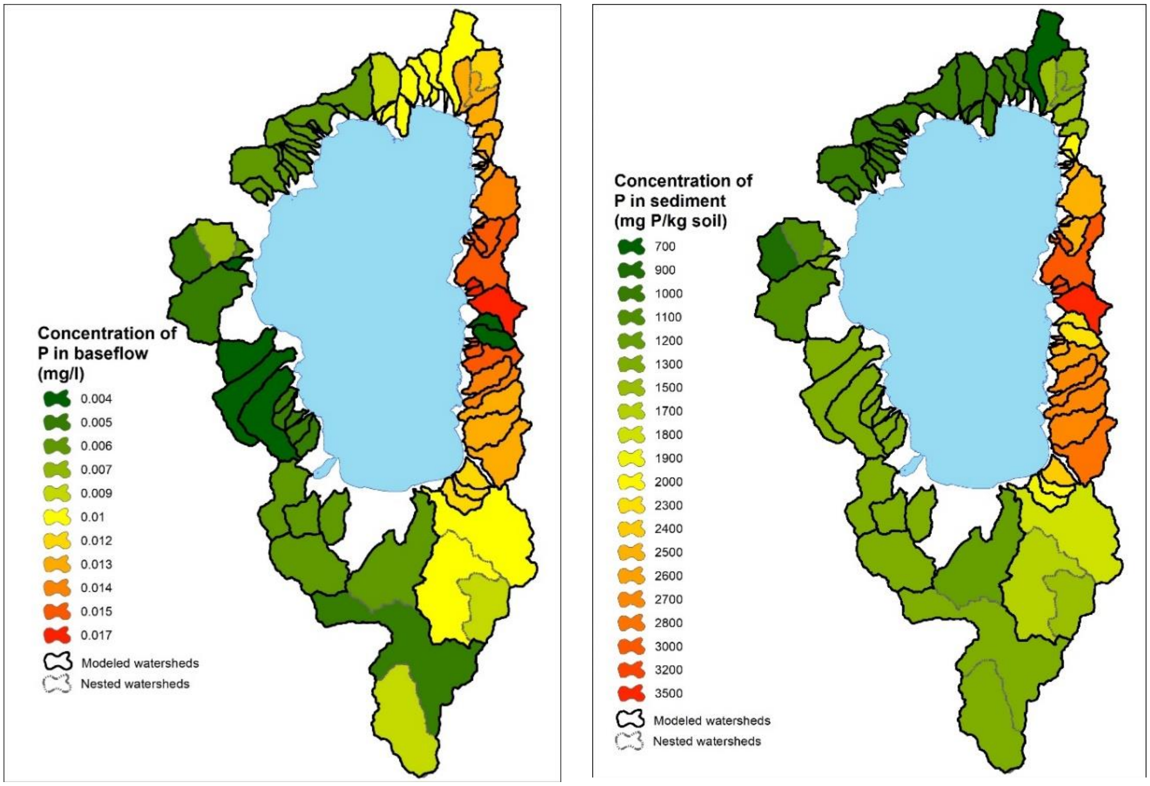


Figure A3. Interpolated phosphorus concentrations in runoff, lateral flow, baseflow and sediment from Lake Tahoe basin watersheds in California/Nevada.

Table A1. Watershed information and web links to model runs.

No.	**Name**	**USGS station**	**USGS Name/Watershed Name Location**
			California
1	WC8	10336676	WARD C AT HWY 89 NR TAHOE PINES https://wepp.cloud/weppcloud/runs/lt_202012_63_Ward_Creek_CurCond/cfg/
2	WC7A	10336675	WARD C A STANFORD ROCK TRAIL XING NR TAHOE CITY https://wepp.cloud/weppcloud/runs/lt_202012_63_Ward_Creek_WC3A_CurCond/cfg/
3	WC3A	10336674	WARD C BL CONFLUENCE NR TAHOE CITY https://wepp.cloud/weppcloud/runs/lt_202012_63_Ward_Creek_WC7A_CurCond/cfg/
4	BC1	10336660	BLACKWOOD C NR TAHOE CITY https://wepp.cloud/weppcloud/runs/lt_202012_62_Blackwood_Creek_CurCond/cfg/
5	GC1	10336645	GENERAL C NR MEEKS BAY https://wepp.cloud/weppcloud/runs/lt_202012_56_General_Creek_CurCond/cfg/
6	UTR1	10336610	UPPER TRUCKEE RV AT SOUTH LAKE TAHOE https://wepp.cloud/weppcloud/runs/lt_202012_44_Upper_Truckee_River_Big_Meadow_Creek_CurCond/cfg/
7	UTR3	103366092	UPPER TRUCKEE RV AT HWY 50 ABV MEYERS https://wepp.cloud/weppcloud/runs/lt_202012_44_Upper_Truckee_River_UT3_CurCond/cfg/
8	UTR5	10336580	UPPER TRUCKEE RV AT S UPPER TRUCKEE RD NR MEYERS https://wepp.cloud/weppcloud/runs/lt_202012_44_Upper_Truckee_River_UT5_CurCond/cfg/
9	TC4	10336780	TROUT CK NR TAHOE VALLEY https://wepp.cloud/weppcloud/runs/lt_202012_43_Trout_Creek_CurCond/cfg/
10	TC2	10336775	TROUT CK AT PIONEER TRAIL NR SOUTH LAKE TAHOE https://wepp.cloud/weppcloud/runs/lt_202012_43_Trout_Creek_TC2_CurCond/cfg/
11	TC3	10336770	TROUT CK AT USFS RD 12N01 NR MEYERS https://wepp.cloud/weppcloud/runs/lt_202012_43_Trout_Creek_TC3_CurCond/cfg/

			Nevada
12	LH1	10336740	LOGAN HOUSE CK NR GLENBROOK https://wepp.cloud/weppcloud/runs/lt_202012_31_Logan_House_Creek_CurCond/cfg/
13	GL1	10336730	GLENBROOK CK AT GLENBROOK https://wepp.cloud/weppcloud/runs/lt_202012_29_Glenbrook_Creek_CurCond/cfg/
14	IN1	10336700	INCLINE CK NR CRYSTAL BAY https://wepp.cloud/weppcloud/runs/lt_202012_19_Incline_Creek_CurCond/cfg/
15	IN2	103366995	INCLINE CK AT HWY 28 AT INCLINE VILLEGE https://wepp.cloud/weppcloud/runs/lt_202012_19_Incline_Creek_IN2_CurCond/cfg/
16	IN3	103366993	INCLINE CK ABV TYROL VILLAGE NR INCLINE VILLAGE https://wepp.cloud/weppcloud/runs/lt_202012_19_Incline_Creek_IN3_CurCond/cfg/
17	TH1	10336698	THIRD CK NR CRYSTAL BAY https://wepp.cloud/weppcloud/runs/lt_202012_18_Third_Creek_CurCond/cfg/