T S AC TAHOE SCIENCE ADVISORY COUNCIL

Tahoe Stream Environmental Zones Review

Final Report for the Tahoe Regional Planning Agency

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A Conceptual Model for Stream Environment Zones in the Lake Tahoe Basin

Introduction

The objective for developing a conceptual model and discussion in this topic brief is to help organize a discussion of the ecosystem components, interactions, and drivers that are characteristics of the different types of ecosystems all regulated under the stream environment zone regulations in the Lake Tahoe Basin. This discussion will be presented in topics briefs that follow. For the rationale, we will quote the following statements from the Scope of Work. *"SEZ related standards currently reside in a number of threshold categories, including (soil conservation, vegetation, and wildlife) and while the SEZ are often described as being important or providing a number of benefits, this is often not quantified. This task will involve development of a conceptual model based of the benefits from SEZ and the stressors on SEZ. The model and associated documentation should include a discussion of how the function and benefits derived from SEZs (and or SEZ enhancement or restoration) vary by type, size and location."*

Topic brief A gives a general introduction to the utility of the SEZ (stream environment zone) construct. The subject of Topic brief B is *"Tracking SEZ condition-using the conceptual model as a frame, provide an overview of the benefits/drawbacks of using area as a metric to track the benefits of SEZ restoration and costs of degradation."* Topic brief B will discuss further the values of different types of SEZ, the benefits of restoration, and how restoration goals might vary by type and location. Topic Brief C gives comment on the current work in improving the comprehensive map of SEZ in the Lake Tahoe Basin, particularly in mapping historic SEZ areas that are now altered by diversion, channelization, or filling. Finally, Topic Brief D provides an overview of the potential impacts of climate change on SEZ in the basin and their functions.

Overall organization of the conceptual model

The conceptual model presented here has a tabular style organization (Figure 1, final page). Drivers, Intermediate processes, Values, and Thresholds are arranged on the vertical axis. Along the horizontal axis there is a gradient of natural (on the left) to more anthropogenic values, state variables and drivers on the horizontal axis. This style seemed to convey a lot of organization that is lacking from the more "radial' style of diagrams which seem oriented toward showing interactions. It is organized as follows:
(from the top along the vertical axis):

- **External Drivers (outside the basin),**
- **Drivers inside the Basin,**
- **Intermediate processes,**
- **Stressors (as specified in the scope of work)**
- **State variables,**
- **Values**
- **Thresholds (the quantitative, regulatory expression of values).**

Separate symbols for Stressors (abbreviated by letter codes in red) in order to distinguish them from other Drivers. Many stressors are either physical or biological drivers that are simply outside of the normal range of variability. Perhaps the most relevant example would be the stressor "extreme flows". This stressor is driven by precipitation and temperature (as external drivers) and could be exacerbated by either: climatic extremes, modification of stream topography, or runoff from impervious cover area which would tend to increase maximum flows in streams.

External Drivers

Obviously the management of SEZ's in the Tahoe Basin has little influence on the external drivers (climatic temperature regime, precipitation as snow or rain, or long range atmospheric deposition). However, the processes in the SEZ's can moderate the *effect* of the external drivers on local ecosystems. These effects are indicated in the conceptual model as feedbacks on intermediate processes and stressors. With respect to the effects of climate change, the most important drivers with respect to the aquatic and riparian systems in the basin are rain, snow, ice, and climatic temperature regime.

Temperature

Temperature as a driver in the model includes long term climatic temperature regime as well as shorter term variation, for example a warm period inducing early spring snowmelt (Dettinger, 2005). It also controls the shift between liquid precipitation and snow.

Frozen and liquid precipitation

Frozen and liquid precipitation is shown separately because of the fundamentally different storage times before they enter groundwater and streams and appear in the hydrograph. The arrows linking frozen and liquid precipitation are meant to indicate the hydrologic importance of a shift between frozen and liquid precipitation, and the arrow linking the "valve" between them to climatic temperature regime allows consideration the anticipated effect of the shift from snow to rain with climatic warming. This aspect will be discussed in more detail in topic brief D along with anticipated effects of altered hydrographs and possible increased evapotranspiration on riparian ecosystems.

Atmospheric deposition

Atmospheric deposition of nitrogen and phosphorus is not strictly "external". While there is long range deposition of N and P, there are also sources within the basin caused by traffic, road dust, and pollen (Dolislager et al., 2012). Atmospheric deposition of nutrients and affect streams and wetlands as well as Lake Tahoe itself. Snow in the Sierras contains substantial concentrations of nitrate that finds its way into streams and wetlands and peaks during snowmelt (Sickman et al., 2003). These peaks of nitrate were observed in an artificial wetland in Tahoe City (Heyvaert et al., 2006) but were largely assimilated by the wetland. In ultra-oligotrophic fens, deposition of dust from roads may cause phosphorus enrichment and succession to more nutrient adapted species.

The applicability of the SEZ construct with respect to external drivers will be discussed though the more specific applicability to internal drivers and stressors (such and the ability of riparian vegetation to moderate the flood hydrograph).

Internal Drivers, Stressors, and Intermediate processes

As specified in the proposal for the development of the conceptual model, we separately indicate stressors, external, and internal drivers. In conceptual modelling of ecosystems, the inclusion of stressors is common (for example Scott et al., 2005, or Fremier et al., 2008).Here we have included those that ultimately negatively affect the attainment of the values indicated in the diagram. Thus, some stressors are just the extreme effects of normal external or internal drivers, or even intermediate processes. These can be considered as examples of the ecological "subsidy-stress curve" (Odum et al., 1979) where "drivers" become "stressors" at some extraordinarily low or high level. These are indicated in red letters rather than with oval boxes and curved arrows simply to avoid the proliferation of arrows.

Another template for conceptual models was developed by the European Environment Agency; the DPSIR framework (Driving forces, Pressure, State, Impact, Response), (Smeets and Wetering, 1999). In the original report proposing this framework, Smeets and Wetering briefly defined the relationships between these elements with the following: "Driving forces and (ii) the resulting environmental Pressures, on (iii) the State of the Environment and (iv) Impacts resulting from changes in environmental quality and on (v) the societal Response to these changes in the environment." Because it was originally conceived in the context of environmental policy, the driving forces were human caused forces such as population growth, transportation, or the fisheries industry (Kristensen, 2004). This use differs from "Drivers" or "forcing functions" as usually presented in ecosystem models (Hall and Day, 1990) and its use in this report which would include natural processes. In an EPA guidance document Bradley and Yee (2016) add this observation: "Note that because *Driving forces*, in DPSIR terminology, arise from fulfillment of human needs, they do not include the natural external influences (such as climate and weather) typically referred to as *forcing functions* in ecological modeling." Kristensen defined "Pressures" as follows. "Human activities exert "pressures" on the environment, as a result of production or consumption processes, which can be divided into three main types: (i) excessive use of environmental resources, (ii) changes in land use, and (iii) emissions (of chemicals, waste, radiation, noise) to air, water and soil." These human caused "pressures" correspond to anthropogenic "stressors" as used in ecosystem models, but would not include natural "stressors" such as drought and would not correspond to the "subsidy-stress" model of Odum et al., 1978). "State" or "state variables" are used in the same sense in both this report and the DPSIR framework. Thus, the nomenclature of the DPSIR framework would not correspond in all cases to the uses of "drivers" and "stressor" as used in this report, although there would be considerable overlap.

The feedback from state variables or intermediate processes express how management of SEZ's can moderate the stressors. Perhaps the best example of this, again, is the moderation of the flood hydrograph by riparian vegetation and wetlands (Mitsch and Gosselink, 2015), as well as in sediment transport in the effect of the stressor "extreme flows". The diagram also indicates the interaction of the stressors of bark beetle damage, catastrophic wildfires, erosion and extreme flows. Scientific support of the effect of catastrophic wildfire, massive upslope erosion and the accumulation of the debris flow in a riparian zone after the Gondola Fire was documented in Carroll et al., (2007).

Before describing each of the drivers and stressors and their effects on system function, we will introduce the state variables in the next section since that is what the drivers and stressors affect.

State Variables

In the conceptual model (Fig. 1). State variables are shown in a separate row(s) of boxes (also listed in Table 1). It is common to indicate state variables in conceptual models as physical components of the ecosystem that can be characterized with one or more *attributes* at a particular time and place (Hall and Day 1990). An example from the Figure 1 would be riparian "terrestrial vegetation", with *attributes* of biomass (g/m^2), and leaf area (m^2/m^2), and areal extent (ha), all of which would be function of time. Leaf area in the riparian zone interacts with external radiation and temperature (external drivers) to moderate stream temperature. Additional examples for riparian ecosystems can be found in Scott et al., 2005, or Fremier et al., 2008. The advantage of separately indicating state variables and processes (such and drivers, and stressors) is that causes, effects, and interactions are show more explicitly. For our discussion of the appropriateness of the SEZ construct (see Topic Brief A) it helps differentiate the effects of conservation or restoration of specific state variables. An example would be riparian terrestrial vegetation and its interaction with other state variables. Terrestrial vegetation affects streamwater, a state variable, by affecting water temperature of streams through shading. Boles and limbs from terrestrial vegetation falling into streams also contributes to large woody debris (another state variable that then affects channel geomorphic functions (a process in the model).

The relative importance of each of the state variables in four types of SEZ in indicated in Table 1. These are all subjective and could be subject to ranking by a panel of experts. The types of SEZ's represent the major categories outlined in the TRPA code *53.9.1. SEZ Identification* with a few exceptions. We did not include **lakes and ponds** because, (1) they would require a fundamentally different model, and (2) we did not expect that they would be a major target for development or restoration. Fens and other types of marshes would be more accurately portrayed separately because of the fundamental nature of sustained groundwater flow in maintaining fens (Mitsch and Gosselink, 2015). While the drivers for both fens and other types of marshes are liguid precipitation, Snow/sleet/, and the internal driver runoff and erosion, the hydrologic pathways (arrows in the model) between Stream/lake water, groundwater, nutrients and biota differ.

Table. 1. State Variables: Important inorganic or biological components of the system that have mass, or area or some other variable property. The relative importance of each state variable in four types of SEZ's is indicated on a scale of 0 – 5, with 5 being "very important". "Relative importance is defined as the impact of each state variable on the overall structure and function of the ecosystem in each type of SEZ.
*Impermeable surface draining *into* each of the types of SEZ *from outside* the SEZ itself is included in the impact on the SEZ.
** for beaches the importance of lake level is indicated under the state variable "Stream/lake water"

State Variable	**Classification**	**Streams**	**Wetlands**	**Wet Meadows**	**Beaches**
Impervious cover *	anthropogenic	5	1	0	2
Aquatic plants	biota	2	5	5	1
Aquatic animals	biota	5	5	5	1
Terrestrial plants	biota	5	1	2	2
Terrestrial animals	biota	5	1	3	2
Nutrients	biochemical	5	5	5	1
Stream/lake water	hydrologic	5	5	2	5 (lake level)**
Groundwater	hydrologic	4	5	5	2
Stream or beach substrate	substrate	5	-	-	5
Soil/peat	substrate	0	5	5	0
Large woody debris	substrate	4	1	1	2

"Impervious cover" (aka "impervious surface") was included as a state variable since it can be measured in terms of square km, and because it had been identified as a key parameter affecting runoff (Cablk and Minor 2010). The increase in impermeable surface also is listed as a stressor in its effects in increasing runoff (Attributes for impervious cover, could include: degree of imperviousness (e.g. asphalt or concrete vs. semipermeable materials, slope, connection to streams or beaches (e.g. via direct runoff, ditches, detention basins, properly cleaned drop inlets), and areal extent. Since drainage to streams and beaches may come from impermeable surface outside the SEZ, all impermeable surface eventually draining to an SEZ should be included along with areal extent.

The state variables for *biota* are grouped together within a dashed line but includes aquatic plants, aquatic animals, terrestrial plants and terrestrial animals. The distinction between terrestrial and aquatic plant is a simplification, especially for emergent wetland plants, but we might arbitrarily place obligate wetland plants in the "aquatic plant" category, and facultative wetland plants in the terrestrial plant category. Willows, alders, and cottonwoods would be much more obvious riparian species that would be placed in the terrestrial plant category.

These state variables interact as depicted by the arrows connecting them. For example, aquatic animals such as mayfly nymphs eat aquatic plants, such as algae, and algae are lumped with aquatic plants at this level of aggregation. The abundance of algae may also place constraints on the mayfly population if there is insufficient algae to support a larger population, an example of the interaction shown by double-headed arrows. One of the special characteristics of riparian zones and wetlands are the interactions of terrestrial plants and animals with aquatic plants and animals (Mitsch and Gosselink, 2015) through processes such as litterfall into streams, predation by terrestrial animals such as the dipper in streams, or bears feeding on spawning salmon.

Decomposers are not depicted as a state variable but may be implicitly involved in transformations of plant detritus and interaction with nutrients indicated as an interaction. Plant detritus could be regarded as part of the substrate in streams or the soil in terrestrial riparian areas, and peat in peatlands.

Nutrients are depicted as a state variable interacting with the stream, lake, and groundwater, and the aquatic and terrestrial plants. The major nutrients could be given attributes such as element, species, concentration (mg/L), % dissolved inorganic, % dissolved organic and % in particles less than 20 um (Heyvaert et al. 2016), % in particles larger than 20 um, a status as “limiting” or “non-limiting”.

Stream/lake water and groundwater are also state variables that can be described with attributes such as discharge, velocity, stage/lake elevation, and temperature. In the case of groundwater, depth below surface, elevation, flux and direction would be attributes. Each of these would be specific for a place and time. Groundwater depth and direction of flux is the most difficult to monitor, but critical for delineating the riparian zone for stream SEZ’s. The important exchanges between streamwater and groundwater are shown as an important interaction in the model since surface water serves both the discharge and recharge groundwater in the SEZ’s, often with complex paths in the hyporheic zone. This interaction should be considered one of the most important in restoration (Hester and Gooseff, 2010). Restoration efforts should insure the wetted perimeter and the hydraulic conductivity of the substrate is maximized, where appropriate, in groundwater recharge zones.

In the case of beaches, “stream/lake water” would be described by the attribute of lake level elevation because of the importance of high lake levels in erosion. For beaches, groundwater would be described by the attribute of elevation or depth below surface which is also importance during droughts when hydrophytes may be stressed.

Substrates in streams, beaches and in soils are described as state variable. In the soil and peat of wetlands and riparian zones the hydraulic conductivity, oxygen content and cohesiveness are important attributes that interact with groundwater, and indirectly with terrestrial and aquatic plants. Indirect effects are indicated in the model where state variables are connected via another state variable (e.g. soil/peat is connected to groundwater which is connected with streamwater and then biota). Cohesiveness also affects the potential for erosion for the riparian zone, streambed, and beaches (Simon et al., 2010). Cohesiveness, or resistance to erosion afforded by cobble size rocks is one of the most important considerations during restoration. Stream substrates may be described by the attributes of particle size classes (% sand, %gravel, % cobbles, etc.) which additionally serve a complex habitats for periphyton, invertebrates, fish and as fish spawning substrates (TRPA 2015). The size of the spaces between gravel or stones may be as important as the size of the material itself as a habitat for meiofauna and benthic animals such as salamanders. Finally, large woody debris is described as a state variable because it is widespread in the forested basin, it provides resistance to extreme flows, stabilizes banks, and it a substrate for aquatic invertebrates. Attributes describing large woody debris could include biomass/m^2, and surface area perpendicular to flow. Woody debris may also be important on beach SEZ’s, reducing erosion and providing cover for fish.

In the special category of SEZ's with a peat substrate, the degree of saturation with water and oxygen interstitial oxygen is important in that lowering the water table and the subsequent exposure to oxygen can cause subsidence and oxidation (Mitsch and Gosselink, 2015). Consequently, drainage is an important stressor in peat soils such as those in the Tahoe Keys area.

Internal drivers

Topography

In the steep mountainous terrain of the Lake Tahoe Basin, *topography* imposes an especially important driving force to stream environment zones and creates clear differences in type of SEZ's. Stream riparian zones can be distinguished as lying along high gradient or low gradient streams. Along high gradient streams, the riparian zone is most often limited in width. Low gradient streams tend to occur in three- elevational zones, (1) in the alluvial soils deposited along the borders of Lake Tahoe when it was at a higher level, (2) by sedimentation or volcanic debris flows, or (3) at higher elevations in depressions in glacial cirques and behind moraines (USDA NRCS, 2007). Wetlands and wet meadows also occur in both lower and higher elevation depressions along streams and seeps. In the conceptual model, arrows depict the effects of topography in driving runoff and erosion, channel geomorphic functions, in modifying the effects of extreme flows (e.g. through storage in floodplains) and contributing to water quality in streams, lakes and wetlands through erosion.

Runoff and Erosion

Runoff and erosion are depicted as internal drivers of hydrology. They are, in turn dictated by precipitation, and the ratio and timing of liquid vs. frozen precipitation. Snow generally is stored on the surface to slowly generate runoff when it melts, tending to generate less "flashy hydrographs and less erosion. Rainfall from large storm events can generate runoff within hours, with higher peak lows and thus more erosion. Atmospheric deposition is also depicted as affecting runoff in the sense of contributing nutrients to runoff. The driver "runoff and erosion" is depicted as inputs to the state variable "stream and lake water", which interact with "groundwater". Urbanization and infrastructure also drive runoff and erosion through the proliferation of "impermeable surface".

Fire

Fire is also an important driving force. Fire is believed to have always played a large role in the subalpine forest of the Sierra Nevada (Raumann and Cablk 2008). Currently the driving force of "fire" can be distinguished by three categories: fire suppression, wildfire, and controlled burning. Thus in the diagram, fire affects vegetation condition and catastrophic wildfire, but also interacts with the stressors of drought, and beetle damage.

A complex interaction between fire and SEZ vegetation is indicated in the diagram as an interaction with the stressor "conifer encroachment (illustrated in the model by an arrow from "vegetation condition" to "fire" labelled as a stressor "ConfiEnc"). Fire suppression is believed to have led to the decline in area of trembling aspen communities and, perhaps, wet meadows in the Sierra Nevada (Kuhn at al. 2011). Fire suppression has allowed species such as lodgepole pine and white fir to outcompete trembling aspen, an early successional species. This is one example of "*conifer encroachment*". The herbaceous layer in trembling aspen stands in the Sierra Nevada is among the most diverse of any communities (Kuhn et al. 2011). The significance of trembling aspen stands for SEZ regulation in the Tahoe basin is that one survey found that 48% of aspen stands in the LTBMU (Lake Tahoe Basin Management Unit) occurred in riparian zones, and another 20% occurred in meadows (wet or dry not indicated) (Sheppard et al. 2006). Thus, riparian zones and meadows are very important in maintaining aspen stands. Controlled burning has been experimentally used to attempt to control conifer encroachment in the Tahoe Basin. The *values* that are affected by conifer encroachment are related to "Preservation of functioning wetlands, streams, floodplains and uncommon communities". This complex interaction is indicated in Figure 1 in which "fire" is affected by vegetation condition, also affected by the stressor conifer encroachment, which in turn acts through catastrophic forest mortality to , in turn, affect terrestrial and aquatic plants.

Fire also affects runoff and erosion. The best example of this effect of fire is the catastrophic erosion that occurred after the Gondola fire where a heavy summer thunderstorm caused an extreme flow on the hydrophobic soils left after the fire (Carroll et al. 2007). However, the majority of the eroded mass from the slope of the fire was captured and retained by the riparian zone below the slope. Clumps of *Juncus balticus* in the riparian zone even showed accumulation of ash laden sediment captured above individual clumps. In the diagram this driving force is indicated with an arrow leading from "Fire" to "Runoff and Erosion".

Biological Alteration

Biological Alteration is a general category of driving forces that include the effects of disease (such as bark beetle epidemics), and invasive species, and succession. An example involving natural succession in SEZ's is given in the next paragraph. In its extreme forms it is represented in the conceptual model with effects on vegetation condition, and the stressors of drought, beetle mortality, and effect on plants and animals. Ultimately, these affect the *values* of resilient forests, public health and safety (through fire conditions), sustainable recreation (through fire danger, mortality, and species invasions), uncommon communities (through fire, succession, mortality and conifer encroachment), healthy native biology and foodwebs (e.g. through species invasions), and even water quality.

Secondary succession is a natural process that will also cause biological alteration. For example, succession from previous fires left groves of trembling aspen in many SEZ's (for example the stands bordering Carson Pass, but now many of those are being overtaken by succession to conifers (Sheppard et al., 2006).

Logging and fuel control.

Logging is not a major factor in the LTBMU due to the USFS practices in the basin except for the possibility of salvage logging after wildfire. But, *Fuel control* is a driving force that affects "vegetation condition" and "catastrophic forest mortality" which are intermediate driving forces in the conceptual model. The effects of fuel control interact with the stressors "*drought*" an "*bark beetle mortality*" since both these stressors interact to increase the need for fuel reduction. The weakening of the trees during drought inhibits the ability to expel the boring insects with pitch. Fuel control is important throughout the Lake Tahoe Basin, but insect mortality also affects lodgepole pine and white fir in SEZ's and fires originating outside of SEZ's also burn SEZ's as occurred in the Angora Fire.

Outdoor Recreation

Outdoor recreation is an anthropogenic driver. It is depicted as interacting with a number of *values* and thresholds in the diagram such as “sustainable recreation, fisheries, access and hiking”, and “scenic resources”. Certain aspects of the interaction between outdoor recreation and functional wetlands, streams, floodplains, and uncommon communities are stresses, such as trampling, and disturbance causing erosion could be significant stressors in some SEZ.
Urbanization and Infrastructure is another driver that affects development of SEZ’s and also leads to the proliferation of impermeable surface (a state variable) that can exacerbate extreme flows and lead to sediment input.

Intermediate driving processes

We have distinguished a category of driving processes that are themselves the result of other more fundamental driving forces. These are “Channel Geomorphic Functions”, “Vegetation Condition”, and “Catastrophic Forest Mortality”. To illustrate the distinction between the more fundamental drivers and an intermediate driver, we will use the example of “**Channel Geomorphic Functions**” They are the product of topography as well as runoff and erosion that interact to shape the slope, substrate, and shape of stream channels. And, this intermediate driver is subject to the stressors of extreme flows and increased impermeable surface as shown in Figure 1.
Vegetation Condition is a combination of factors the can reflect the stresses of drought, beetle attack, succession, and invasive species. It is obviously a combination of many attributes that might be disaggregated in more specific models.
Catastrophic Forest Mortality is an intermediate driver that simply distinguishes the degree of change in vegetation condition and is most often the product of wildfire, but also extreme cases of disease.

Stressors

Stressors can be seen as *drivers* (i.e. driving forces) that are outside the boundaries of normal variation or are suboptimal for the ecosystem (Odum et al. 1979). They are indicated with letter codes in the body of the conceptual model simply to avoid having too many intersecting lines. The major stressors are listed in Table 2 with an assumed value for their relative importance for four different types of SEZ.

Table 3: Relative influence of stressors on different types of SEZ

Stressors	Abbreviation	Streams	Wetlands	Wet Meadows	Beaches
Drought	Drought	5	3	5	4
Increased runoff	Runoff	5	3	3	5
Climate warming & variability	Climate	5	2	4	5
Extreme stream flows or runoff	Xflows	5	1	1	5*

Increased sediment load	Sediments	5	1	1	1
Increased impermeable surface	Imperm	5	2	0	2
Competitive pressure on native species	Comp Pres	4	4	5	5
Bark beetle mortality	Beetle	4	0	3	0
Non-native introduction	NN-Intro	5	2	3	5

* High lake levels rather than high streamflows in this case

Climate, drought and runoff

The effects of climate that are a stressors **climate drought and runoff** are shown at the top of the diagram as affecting all the external drivers (temperature, liquid precipitation, snow/sleet, and atmospheric chemistry). The effects of long term climate change are indicated with these climate related stressors. The effects of these external stressors then cascade through the system via their effects on other drivers, intermediate driving forces.

The Mediterranean climate of the Tahoe Basin and the variations associated with the Southern Oscillation have historically resulted in a number of multi-year droughts in the past (Raumann and Cablk, 2008). While it may be true that SEZ's tend to have more moisture that other areas, they are affected by drought. Many species are dependent on saturated conditions (e.g. in wetlands). Stream channels may become intermittent, blocking movement of aquatic animals. Beach vegetation may be stressed lake levels remain below average for long periods of time. The effects of drought on vegetation condition are indicated in Figure 1 as a stressor, but also groundwater, and stream/beach substrate are affected indirectly by drought through the effects on runoff and erosion and channel geomorphic functions. As noted before, drought affects vegetation condition which increases susceptibility to beetle attack.

Shoreline erosion tends to occur higher lake levels, in particular above 6227 ft. (Adams et al, 2004). Beaches may be susceptible to erosion when climate and runoff allow higher lake levels. However, during low lake levels, streams may also temporarily experience incision near the shoreline. This is indicated in the model by the arrow from "stream/lake water" (through the attribute "lake elevation" to "runoff and erosion".

Extreme flows

Extreme flows affect runoff and erosion, channel geomorphology.and thus can negativity affect SEZ.Topography can exacerbate the effects of extreme flows in steeply sloped areas (see arrow connecting "Topography and "Runoff and Erosion". These are indicated in the diagram in Figure 1. They are also shown negatively affecting vegetation condition in SEZ's through flood damage and sedimentation. The combined effects of catastrophic wild fire and extreme flows in the example of the Gondola fire have already been discussed (Carroll et al. 2007).

Increase in impermeable surface

An increase in impermeable surface area is also depicted as a stressor in the diagram via its effects on runoff and erosion and channel geomorphic functions, not only by increasing extreme water discharge but delivering sediment from paved surfaces (Heyvaert et al. 2016).

Sediment

Excessive sediment is indicated as a stressor on stream and lake water, nutrients, and biota. Excessive sediment carries nutrients (particularly phosphorus, Heyvaert et al. 2016), and can cover the habitats of aquatic plants and animals. Excessive sediment is also a stress to the near shore zone, impairing clarity (Heyvaert et al. 2016). It results not only from extreme flows, but is also the product of streambed degradation and urban runoff. On the other hand riparian areas can serve as a reservoir for excessive sediment loads, one of the chief benefits of riparian areas. The Gondola fire again serves as a good example of this benefit, where large quantities of soil from the surrounding slope were deposited in a forested riparian area within an intermittent watercourse. The vegetation seemed to be resilient to the deposits of sediment with rushes simply growing through the surface and no obvious tree mortality (Carroll et al. 2007 and R. Qualls, personal observation.).

In the case of beaches, sedimentation from the mouths of streams may not be very important in terms of supplying the sand size particles for maintaining beaches. Adams and Minor (2002) reported that the origin of most material in beaches sediments likely originated from backshore erosion (Adams and Minor 2002). The effects of high lake levels (such as those occurring in 2017) and the resulting erosion are probably the most important stressors.

Competitive pressure from biological stresses.

Competition among species is a natural process in the ecosystems found in SEZ's, but in this case we only consider extreme competitive stresses that originate from disturbance or non-native species. We will consider the introduction of non-native species as a separate stressor because of its importance and differences in management. One example of competitive stress is the result of channel incision, or diversion, in wet meadows where the lowering of the water table allows plant species such as grasses and forbs adapted to the dryer conditions to outcompete and overgrow obligate and facultative wetland species (Long and Pope 2014). Thus, both native and non-native species may be involved in these competitive pressures.

Conifer Encroachment.

One type of competitive stressor that is considered as a specific stressor is the encroachment of conifers on aspen groves and wet meadows. The trembling aspen is an early successional species that is replaced by later successional species in the absence of fire. Fire suppression is believed to be leading to the replacement of many aspen communities by conifer species in the Lake Tahoe Basin (Shepard et al.2006, Kuhn et al. 2011). The association with SEZ's are shown by a survey of 542 aspen stands in the Lake Tahoe Basin Management Unit. Forty eight percent of the stands were in riparian habitats, 9% associated with springs, 18% in meadow habitats (described as wet in the study) and 3% along ponds (Shepard et al. 2006). About 2/3 of the stands were classified as being in moderate to highest risk of being lost. The most important risk factor was succession to dominance by conifers. In the Lake Tahoe Basin, white fir, lodgepole pine and red spruce are the most common species encroaching on aspen stands.

The indirect interactions that could be inferred from the conceptual model include the influence of fire (a driver) on catastrophic forest mortality in coniferous forest, , encouraging eventual succession to aspen in very moist areas over succeeding years (Shepard et al. 2006). In addition, aspen stands are not as susceptible to carrying fire as coniferous vegetation, another interaction with the drivers of fire and vegetation condition (Shepard et al. 2006).

Wet meadows may be maintained by sufficiently high water tables but lowering of water table elevation is believed to encourage encroachment of conifers into the meadows. In the past grazing may also have contributed to the degradation of wet meadows, which then lead to incision. We have not listed grazing as a current stressor in the Lake Tahoe Basin because of the currently very low incidence of cattle grazing in the Lake Tahoe Basin itself, but grazing was likely very significant stressor in the past.

Non-native species introductions.

Since the Lake Tahoe basin is geographically isolated and drains into a terminal basin, it is inherently sensitive to non-native species introductions (Murphy and Knoff, 2000). It also resulted in a number of endemic species in the basin that require protection from non-native species. Manley (2004) reported 102 non-native species:(16 fish, 2 invertebrate, and 84 vascular plant species) that occupy the basin and have had impacts on ecosystem diversity and integrity. Now, most fish species in the basin are non-native, and the introduction the lake trout (*Salvelinus namaycush*) contributed to the local extirpation of the Lahonton cutthroat trout (Murphy and Knoff, 2000). Although the effects on Lake Tahoe itself are best known, there are effects in streams, as shown in the following example. A study of invasive fish and invertebrate species in the Upper Truckee found the following: *"Seven of the 12 species were native, including the Lahontan redside shiner, Paiute sculpin, speckled dace, Tahoe sucker, mountain sucker, mountain whitefish, and Lahontan cutthroat trout. Five species were non-native including brook trout, brown trout, rainbow trout, bluegill, and brown bullhead. Native species accounted for 76% of fish surveyed while non-native fish accounted for 24% of fish surveyed. An estimated 330 invasive crayfish and 1,589 native western pearlshell mussels were counted."* (Lemmers and Santora 2013). In the larger study of 26 tributary streams, they also stated that all habitats in all 26 streams had been utilized by non-native trout. The stream community would presumably be impacted by predation on, or competition with native species.

Non-native plants are also a potential problem in SEZ such as the aquatic plants Eurasian watermilfoil, and curlyleaf pondweed. In riparian zones, perennial pepperweed and cheatgrass are potential invasive species that might become a problem. A list and basinwide survey of terrestrial or riparian invasive species was presented in Shepard et al. (2006) but the authors noted that in most cases, the degree of invasion has been greater at elevations lower than the Lake Tahoe Basin.

In the conceptual model non-native species are represented as a stressor on the entire biotic component since they includes both animals and plants, in both aquatic and terrestrial habitats. The further interactions (such and competition, predation, etc.) are included in the interactions between the state variables for plants and animals. The stress of non-native species introduction also indirectly affects the values of "species of concern" "healthy native biology and foodwebs" as represented by arrows from the biota to the boxes for these values. Outdoor recreation and urbanization also plays a role in of non-native species introduction.

Values

Eight different categories of *values* are listed in the conceptual model on a line near the bottom. These "values" might also be called the subjects of "desired outcomes' as expressed in many environmental statements. Some are mainly ecological while some such as "Sustainable Recreation (fisheries, access, hiking), and "Public Health and Safety" are more anthropocentric. Most of these values were either extracted or aggregated from the "Thresholds" as used by TRPA. We have added "carbon sequestration/ greenhouse gas mitigation to those included in the "thresholds" although it could be regarded as included in the Threshold for "Air quality"

We have discussed the relationship of the “values” and thresholds” in Topic Brief A. The historical link between *values* and “Thresholds” was expressed in the 2015 Threshold Evaluation report (Tahoe Regional Planning Authority, 2016) when it stated that the Bi-State Compact defined a threshold standard as “...an environmental standard necessary to maintain a significant scenic, recreational, educational, scientific or natural *value* of the region or to maintain public health and safety within the region." (italics added by authors). This definition was provided in the 1980 revision of the Bi-State Compact, which introduced the concept of a threshold standard. Thus the “Thresholds” express both the underlying values and the quantitative standards necessary to maintain those values.

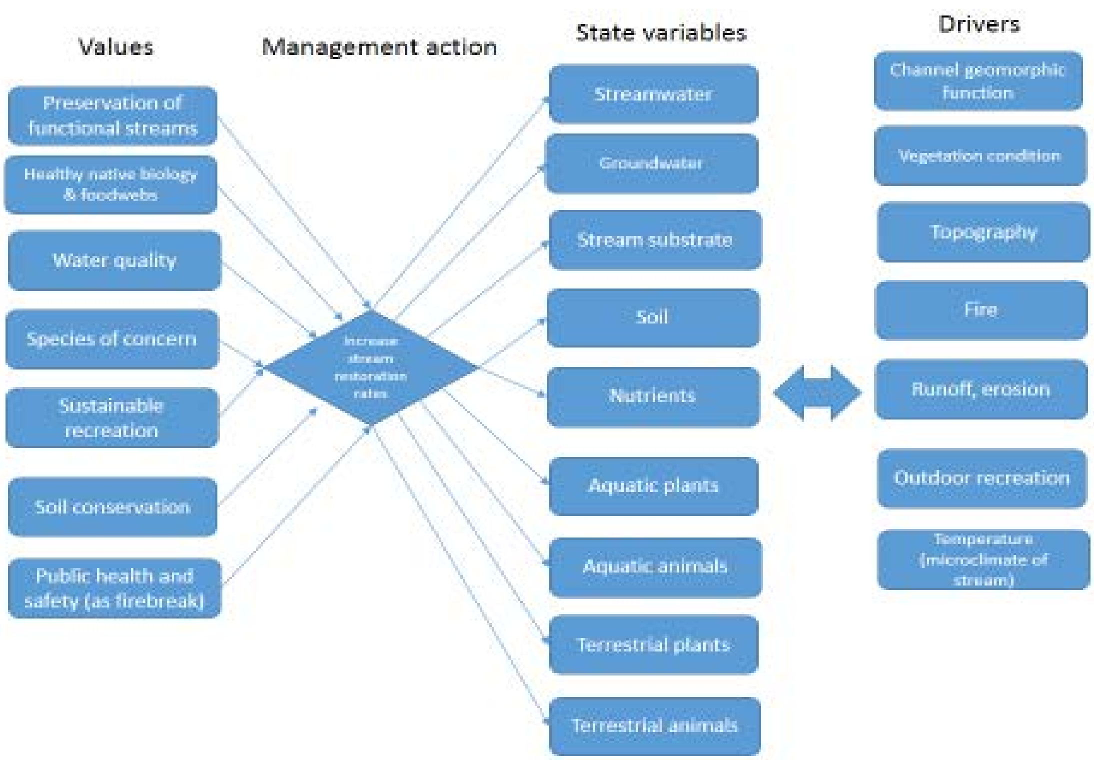
Table 3. Relationship of “values” to “Thresholds recognized by TRPA. Note that “Thresholds” include both the underlying societal/ecological values, and quantitative standards or targets.

Values	**Thresholds**
Water quality in streams, lakes, wetlands	Water quality Scenic resources
Healthy native biology and food webs	Fisheries Wildlife Vegetation preservation
Species of concern	Vegetation preservation Wildlife Fisheries
Preservation of functional wetlands, streams, floodplains, uncommon communities	Vegetation preservation Soil conservation Scenic resources
Sustainable recreation (fisheries, access, hiking)	Recreation Scenic resources
Public health and safety	Air quality, water quality, noise
Resilient forests	Vegetation preservation Scenic resources Soil conservation
Carbon Sequestration/Greenhouse gas mitigation	Air quality, (indirectly) Soil conservation

Use for management actions

These values listed in Table 3 can serve as impetusany management or restoration process. The use of the conceptual model for a management action is illustrated in Figure 2. ***Management actions*** should begin with ***values*** that serve as the rationale for the actions. Management actions might also be termed “Responses” in the DSPIR framework. These are extracted from the conceptual model for the action of increasing the area of streams restored. These are all shown feeding into the management action with arrows as the “cause” for the management action. Then the management action (restoration) would ideally lead to (“cause”) positive or negative effects on pertinent state variables as indicated with arrows to the column of state variables. An example would be a stream restoration project that installed a more natural mixture of cobbles and gravel to improve the substrate , and lessenedthe degree of incision. The resulting higher groundwater improves both vegetation and animal state variables. The connections referenced above are all shown in the conceptual model. The attributes of the state variables can serve as a quantitative measure of success, for example, the % cover and leaf area index of the terrestrial vegetation. These specific quantities for the attributes should be derived from some reference site that is considered a natural example of the particular type of stream (e.g. perennial high gradient stream).

Figure 2. Illustration of the use of the conceptual model for a management action. ***Management actions*** (diamond shape) should begin with ***values*** (boxes in column on the left) that serve as the rationale. Note that there is a cause and effect relationship implied from left to right, with the exceptions of interactions shown with a double arrow.For example, the value "Preservation of functional streams is the impetus for the management action "increase stream restoration rates" which causes improvement of stream substrate, which interacts with the drivers such as channel geomorphic function.



In Figure 2, the major drivers are listed in the fourth column by an arrow that indicated interaction. The drivers affect the state variable in the ways indicated in the conceptual model, but for internal and intermediate processes, there are also feedbacks in which improvement in the state variables can modify the drivers. An example, a favorable effect of "stream substrate" on the driver "runoff and erosion". However, improvements in the state variables are unlikely to affect "external drivers". Thus, the management flow chart in Figure 2 can be derived from the values, state variables, drivers and their interaction (indicated with arrows) shown in the conceptual model in Figure 1.

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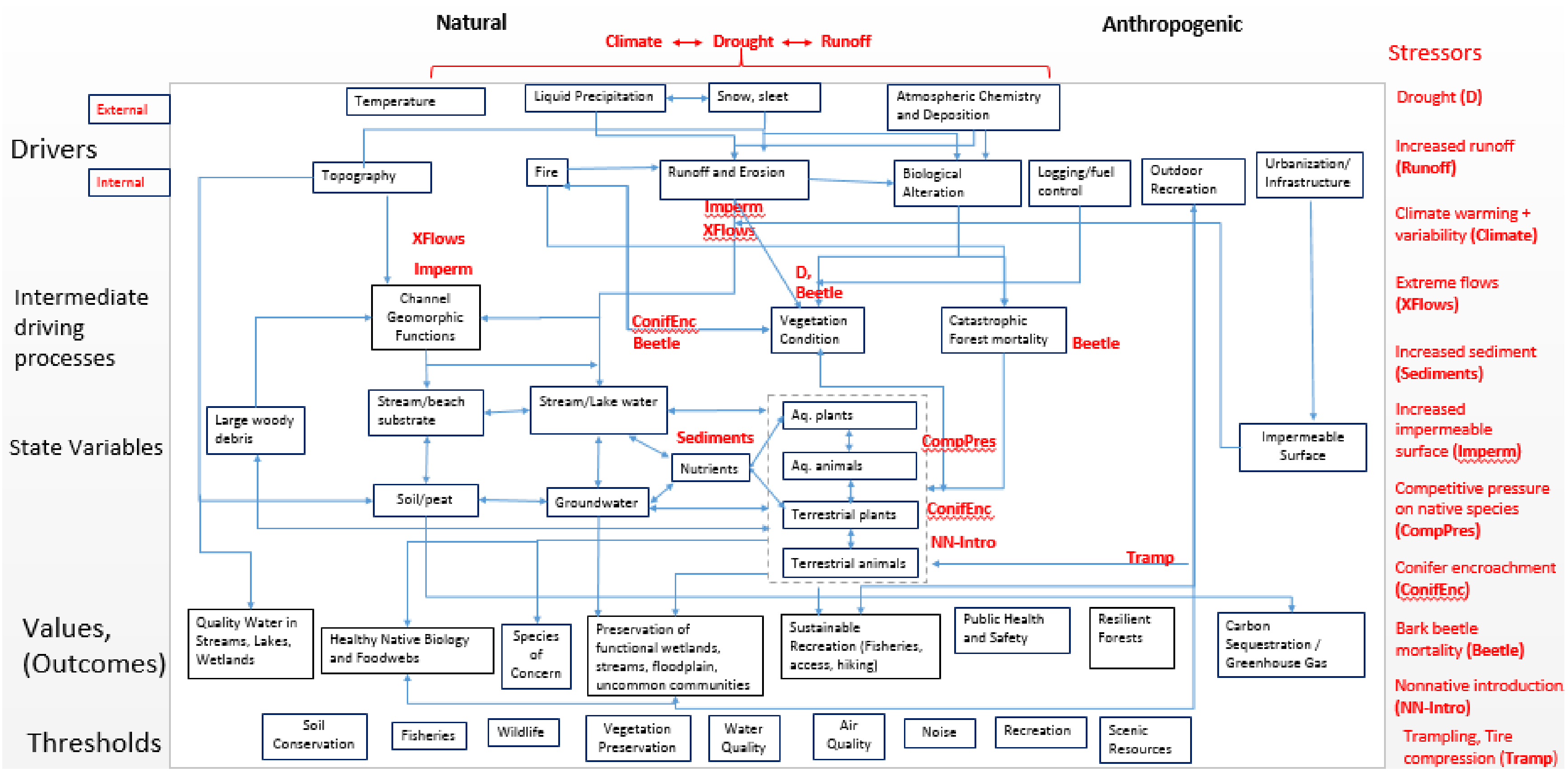

Figure 1. Conceptual model for Stream Environment Zones in the Lake Tahoe Basin.

The Utility of the Stream Environment Zone Construct in the Lake Tahoe Basin

Topic Brief A

The threshold standards that call for regulation and conservation of stream environment zones (SEZ) in the Lake Tahoe Basin were adopted on have evolved since they were first established in 1982 and then adopted in the Code of Ordinances in 1987. These have not substantially changed over the years since that time. As they are practiced they have several advantages in promoting the health of the environment in the Lake Tahoe Basin:

(1) They aim to protect not only some environments, e.g. jurisdictional wetlands, but riparian zones along streams, wet meadows, and other water associated environments.
(2) Included in the values placed on SEZ's (aka "Thresholds"), are provisions for conservation of "uncommon communities" , a concept more inclusive than the conservation of "threatened and endangered species", implicitly recognizing the importance of habitat in conservation.
(3) They effectively seek to regulate the watercourses within entire watersheds, thus effectively recognizing the hydrologic connectivity of the aquatic ecosystems from ephemeral streams to Lake Tahoe.
(4) They have a well-established set of values that include those that range from ecological (e.g. preservation or uncommon communities, to more anthropocentric values such as noise abatement and the aesthetic (e.g. scenic vistas). However, we will point out the difficulty equating these values among different types of SEZ's.
(5) They have a long established "buy in" from local and regional governments which is remarkable given the jurisdiction of two states, five counties and numerous communities with coordination provided by the Tahoe Regional Planning Authority.

In general the primary motivation for updating the current construct of the SEZ would be in assigning more goals for restoration. Updating the SEZ construct in may involve two more specific actions: (1) setting new goals for restoration, for example more restoration of SEZ's that have been completely eliminated ("historic SEZ's") or degraded, and (2) a system for prioritizing communities or segments for restoration. As a generality, most environmental regulations tend to evolve over time as exemplified by the Clean Water Act, which, since the 1972 Act, has added amendments such as section 303d to control non-point sources. But these "updates" are most often accomplished by executive agencies (such as changes in TMDL goals by State executive agencies). These advantages and suggestions for improvement will be discussed in relation to the conceptual model of stream environment zones shown in Figure 1.

The context for the appropriateness of the SEZ regulations in the Lake Tahoe Basin must take into account the unique aspects of the Basin. Firstly, the eutrophication of Lake Tahoe itself has historically been the center of concern, but the protection of streams, riparian soils, and wetlands have long been recognized as central to preventing sediment and nutrient inputs. Secondly, the U.S. Forest Service is the steward of 78% percent of the basin, including most of the upslope portions of the watershed that might otherwise be susceptible to erosion. The basin contains essentially no agriculture and only a very limited amount of grazing land (Raumann and Calbk 2008, TRPA 2015). The remaining portions of the non-forested land regulated by the USFS is comprised largely of ski slopes, other recreation, and related infrastructure including access roads. Thirdly, the Lake Tahoe Basin is more susceptible to catastrophic wild fire than many comparably regulated watershed regions due to the Mediterranean summer drought climate, fire suppression, and beetle damage, (Raumann and Calbk 2008) which can cause severe sediment and nutrient inputs to Lake Tahoe (Carrol et al., 2007). Finally, the economy of the Lake Tahoe Basin is centered on recreation and tourism that depends on natural scenic vistas (Tahoe Regional Planning Authority, 2016). Consequently, there is widespread public, and business support of measures that protect many of the values expressed in the "Thresholds".

Values and "Threshold Categories"

We will begin our discussion of specific aspects of the SEZ construct with "***values***". These are indicated in the next to last line of Figure 1. We will use the term *values* since it is the term more widely used in environmental policy (Mitch and Gosselink, 2015). The historical link between *values* and "Thresholds" was expressed in the 2015 Threshold Evaluation report (Tahoe Regional Planning Authority, 2016) when it stated that the Bi-State Compact defined a threshold standard as "...an environmental standard necessary to maintain a significant scenic, recreational, educational, scientific or natural *value* of the region or to maintain public health and safety within the region." (italics added by authors). This statement refers to the 1980 revision of the Bi-State Compact and the threshold standards. Thus the "Thresholds" express both the underlying values and the quantitative standards necessary to maintain those values. These thresholds were not specifically developed for SEZ regulations, but were for more general regulation of environmental quality of the entire Basin. However, each Threshold Evaluation report (mandated every five years) discusses how each individual Threshold applies to SEZ's in explicit sections. Thus most, if not all of the values expressed in the "Thresholds" can be applied to SEZ's.

The nine Threshold Categories are: water quality, soil conservation, air quality, vegetation preservation, wildlife, fisheries, noise, recreation, scenic resources. These may be slightly restated to read as "values" (e.g. preservation of water quality). Some of these general thresholds categories may be more obviously supported by SEZ's; water quality, soils conservation (especially for riparian soils), vegetation preservation (e.g. riparian aspen groves or fens), fisheries (e.g. spawning habitat), recreation (e.g. streamside trails), and scenic resources (SEZ's as "green space corridors). In Figure 1, the values are ordered left to right from those more associated with natural conservation to those more anthropocentric values (e. scenic resources). The arrows connecting the various state variables to the values in Fig. 1 show these relationships. Even values which may appear less specific to SEZ's are related. For example, the 2015 Threshold Evaluation report (Tahoe Regional Planning Authority, 2016) cites data that suggest that 75% of wildlife species are associated with SEZ's. Many studies have shown the benefits of strips of vegetation in reduction of traffic noise, both in physical and psychological terms (Anderson et al. 1984) although in none of those studies in the literature were they riparian vegetation.

The state variables for living components of the ecosystems are grouped into a set of boxes enclosed in a boxes with a dashed line to simplify the many input and outputs of the biotic components. For our discussion of the appropriateness of the SEZ constructs, this also helps relate the state of the biotic state variables to more general values such as preservation of uncommon communities.

Hydrological connectivity and watershed level conservation

One of the great advantages of the SEZ construct is the extension of coverage from headwaters, fens, wet meadows, down to higher order streams, intermediate wetlands, and finally to beaches and lakeside riparian zones. On the other hand, each segment or "type" of SEZ in the watershed continuum may have different values and different priorities for protection.

In our conceptual model, we explicitly show exchanges with groundwater. In addition, in a more detailed model of stream SEZ's we could disaggregate the streamwater box into: (a) ephemeral streams, (b) 1st order streams, (c) 2nd order streams, (3) 3rd and higher order streams, (4) wetlands (either fens, or surface water fed wetlands along the water flow path. All of these would have exchanges with groundwater. Thus, the SEZ construct has the potential to cover a large portion of the system of hydrologic connections from source to Lake Tahoe. Only the upland portions of the system that feed water in by overland flow (rare in forests except on dry hydrophobic soils, (Carroll et al., 2007) or into groundwater systems where the groundwater levels below the surface are less than the criteria to classify them as wetlands. Fortunately, the U.S. Forest Service can regulate land use in a large percentage of these upland portions of the watersheds.

A particular example of the entire hydrologic connection system can be described from research on the fens in the Washoe Meadow State Park (Sikes et al. 2011, and R.G. Qualls, unpublished data). In this region steep headslope terrain ends in an abrupt transition to moderately sloped area of fens. At the break in slope, groundwater emerges and forms a system of fens about 2 hectares in extent. The lower boundary of the fens is contained by what is believed to be a lateral moraine (R. Qualls, observation) At the end of the fen, part of the flow forms a small stream, and a larger part moves by subsurface flow through the moraine. Below, the moraine there is a large field of sloped, wet, lodgepole pine forest with a water table less than about 50 cm from the surface. Below, this community, the flow of water descends to the Upper Truckee River floodplain, but the groundwater flow descends below the level necessary to classify it as a wetland since the glacial outwash soils have very high hydraulic conductivity. The wetland areas adjacent to the Upper Truckee River likely intercept this flow of groundwater but is difficult to distinguish from that originating from the Upper Truckee. This example illustrates the deficiencies of wetland delineation based solely on the criteria of the Clean Water Act in a steeply sloping watershed with both hard bedrock near the surface and coarsely textured glacial outwash, the complex system of hydrologic connections, and the advantages of including a variety of wetland and riparian areas under a single management unit. The SEZ construct would be able to comprehensively cover the fens, the sloping lodgepole pine wetlands and the Upper Truckee floodplain. It would not cover the intervening area that is neither riparian or wetland, but is deeper groundwater flow to the Upper Truckee River. Although this particular example is one limited portion of one watershed, it illustrates the advantages and disadvantages of the SEZ construct.

Incorporation of values into the SEZ construct

Another great advantage to the current SEZ construct is the close integration to a fairly extensive set of values, i.e. the values expressed in the thresholds. Here we see the influence of the historical link between "Thresholds" as originally applied to the entire basin in the Bi-State Compact. The Bi-State Compact defined a threshold standard as "...an environmental standard necessary to maintain a significant scenic, recreational, educational, scientific or natural *value* of the region or to maintain public health and safety within the region." Thus, from early in the reporting of the mandated Threshold reports, we can see the integration of the SEZ construct discussed in the context of the values expressed in the "Threshold Categories". The regulation of the Stream Environmental Zone this represents a considerable extension of a more comprehensive set of values than many more narrowly focused environmental regulations.

Wetland *and* Riparian Habitats

One of the advantages cited above it the capacity to cover *both jurisdictional wetlands and riparian zones*, which also incorporates the idea of a specific buffer zone distance that may include areas not specifically riparian or wetland. To cite a particular example, Third Creek, just above its junction with Rosewood Creek flows through a steeply sloping ravine (USGS topographic map, 7.5 min. series, Marlette Lake quadrangle). The species composition necessary to classify the zone as "riparian" is only a very narrow width. Since it is steeply sloping, the groundwater level is likely only near the surface in limited areas, and is likely that width of the zone that where groundwater is less that 1.5 ft. of the surface is far less than the height of the surrounding trees. But seems obvious that the zone necessary to shade the creek, and provide a root system to resist erosion would be much wider. Thus, delimiting the SEZ using only the criteria for jurisdictional wetlands would not protect the riparian zone in this example. An illustration of the concept that the riparian zone is more extensive than the jurisdictional wetland zone is shown Fig. 2. A more quantitative diagram for implementation of the "Streamside Protection Area" for the city of North Vancouver is illustrated in Figure 3.

This recognition of the value of riparian habitats, beyond those strictly confined to jurisdictional wetlands has a long history. The value of "riparian buffer strips was recognized in early USDA literature for farms (Skowland, 2012). In addition the role of riparian zones on removing nutrients has long been recognized. In fact there is as unpublished TRPA document from 1971 (Tahoe Regional Planning Agency. 1971) that set fort the usefulness of riparian buffer zones for water quality.

While the TRPA construct for "Stream Environment Zones" was early in its application, and unique in its comprehensive scope and integration with a larger set of values, it is not alone. There are a many laws in many states that seek to regulate disturbances in riparian zones. A large summary of these law and strategies for riparian area protection has been summarized by the National Academy Press (2002). These may be useful for the TRPA to explain to the public the benefits of these regulations. The reference also includes an excellent summary Table of state regulations, whether required or voluntary, as of 2002. The State of Minnesota has just in 2017 begun regulation of all riparian zones in the state requiring a 50 foot buffer zone of vegetation. It even will include man-made ditches beginning in 2018.

Refinements to the SEZ concept for future application

As pointed out in the introduction, there may be some room for updating the SEZ construct in three areas: (1) new goals for restoration, (2) a system for prioritizing communities or segments for restoration, (3) perhaps more restoration of SEZ's that have been completely eliminated ("historic SEZ's" or degraded). Another consideration may be to incorporate "credits" within the SEZ restoration goals for installation of artificial treatment wetlands as a form of mitigation in place of restoration. The Tahoe City Treatment Wetland has been documented to be very successful at removal of N, P, metals, clay and fine silt from a largely urban and residential watershed (Qualls and Heyvaert 2017; Heyvaert et al. 2016). However, it should be recognized that intact riparian zones themselves are very active in removing nutrients from streams (Mitsch and Gosselink, 2015) and additional area of SEZ's would likely improve nutrient removal. Each of the suggestions these will be considered in more detail in other topic briefs to be part of the final report.

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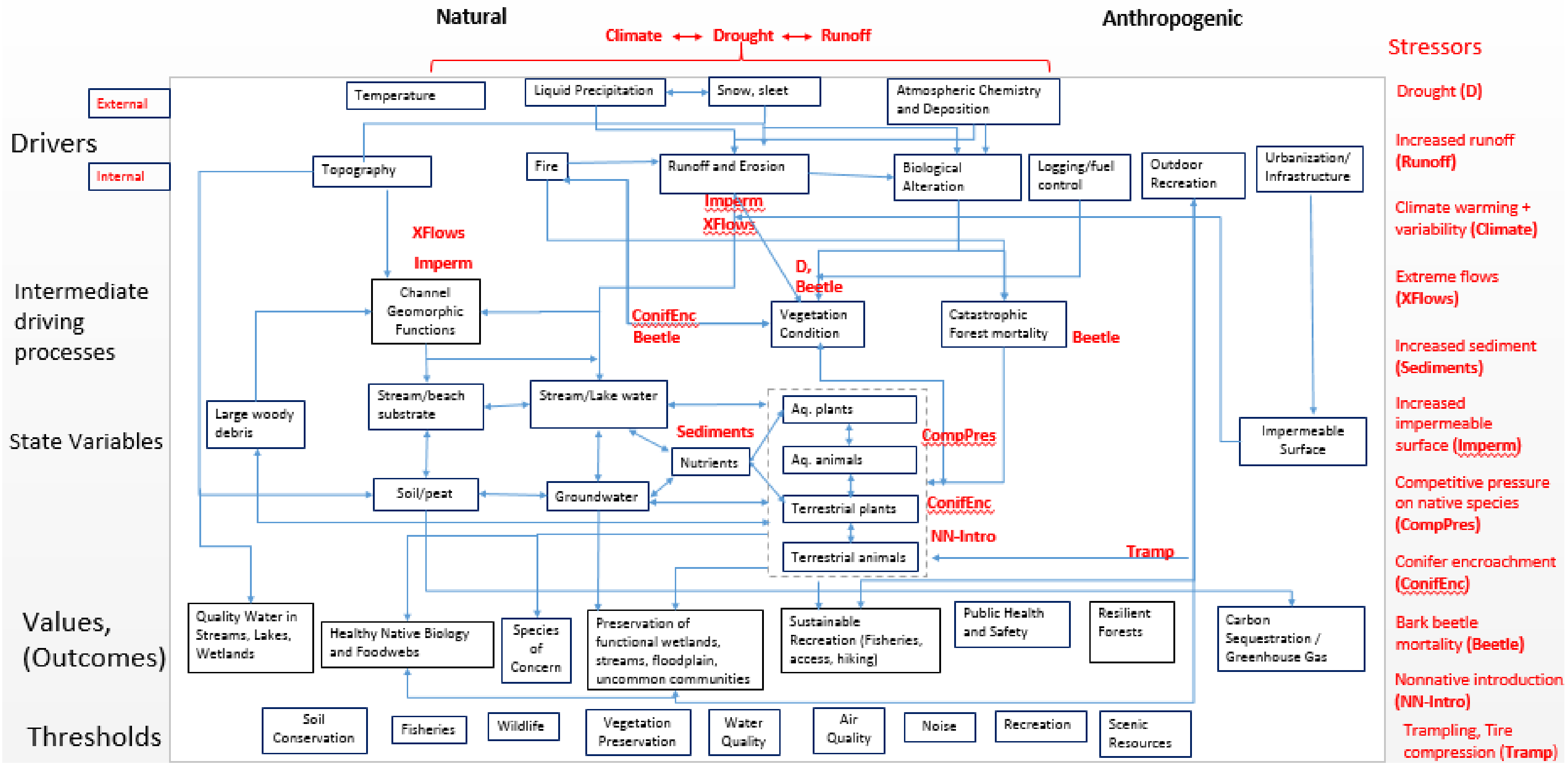

Figure 1. Conceptual model template for Stream Environment Zones in the Lake Tahoe Basin

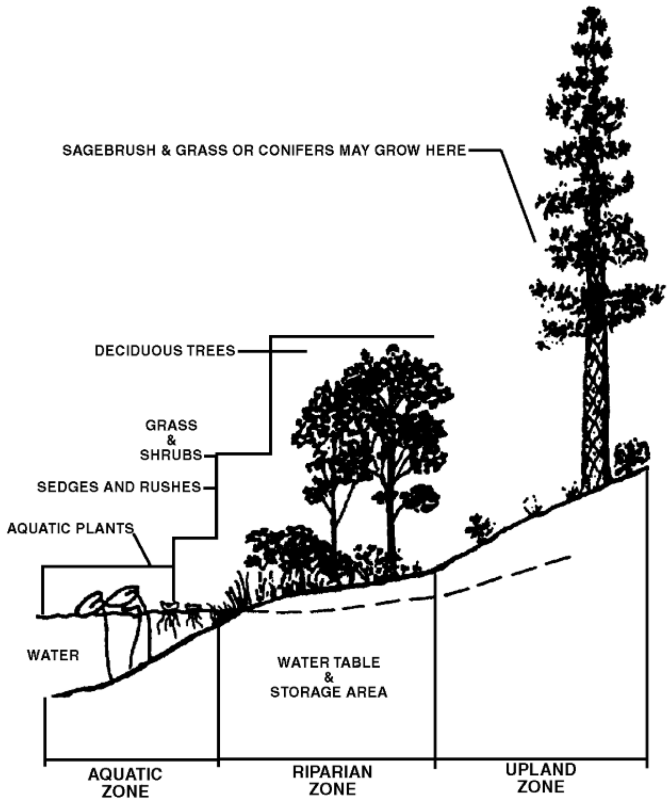

Figure 2. Showing the concept of the "riparian zone" extending beyond saturated soils that would be classified as jurisdictional wetlands, but still dependent on a water table in the root zone. From *The Impact of Federal Programs on Wetlands - Vol. II.* U.S. Department of the Interior.

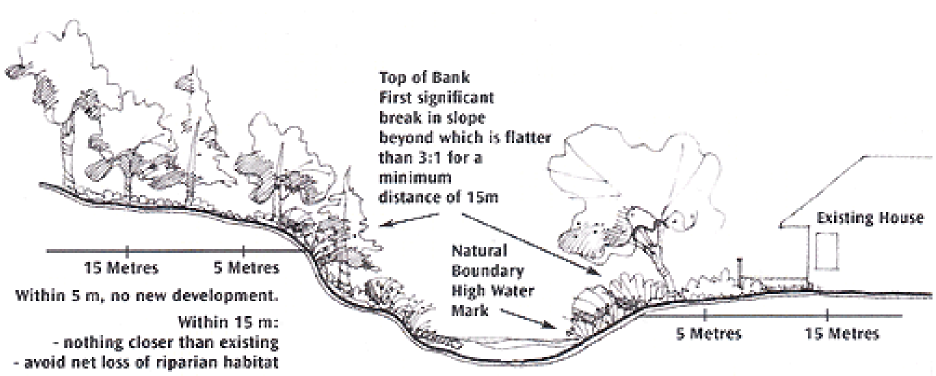

Figure 3. Diagram illustrating a quantitative application of the Streamside Development Permit Areas for the City of North Vancouver. Note that the Riparian zone is defined as extending beyond the natural high water mark.

Topic Brief B, How appropriate is "area restored" for measuring the benefits of SEZ restoration and the establishment of a new restoration target: A prioritization system.

Rationale:

The original regulation which established the definition of Stream Environment Zones (SEZ) also sent goals for restoration:

"Preserve existing naturally functioning SEZ lands in their natural hydrologic condition, restore all disturbed SEZ lands in undeveloped, un-subdivided lands, and restore 25 percent of the SEZ lands that have been identified as disturbed, developed, or subdivided, to attain a 5 percent total increase in the area of naturally functioning SEZ lands." (Quoted from the TRPA, 1982)

In this discussion, we will assume that SEZ that are not degraded or developed will continue to be preserved. Consequently, the focus of this report will be the following four issues:

(1) The need for renewal of the goals for restoration;
(2) Subdivision of restoration goals by type and location of SEZ;
(3) A method of establishing the relative benefits or values of SEZ by type and location;
(4) Approaches for establishing relative priorities for restoration.

The need for renewal of goals for restoration

TRPA issues a Threshold Evaluation Report every five years which gives a detailed discussion of the status of attainment of all values and goals set forth in the "Thresholds" (listed in "Introduction to the conceptual model", http://www.trpa.org/regional-plan/threshold-evaluation/). The report stated that the 5% increase in overall SEZ in the region was attained in 2015 and the 25% goal for restoring "disturbed, developed, or subdivided" is likely to be attained in the near future (TRPA, 2015).

From the very beginning of SEZ regulation there were already two categories of SEZ, (a) those in *undeveloped, un-subdivided lands,* versus (b) those on *disturbed, developed, or subdivided lands.* One criticism listed in the peer reviews of the 2015 Threshold Report was a question of the exact definition of "disturbed vs. undisturbed" (Peer Reviews, Soil Conservation section). The 2015 Threshold Evaluation Report acknowledged the challenge of *"Ambiguous objectives - The standard contains a number of terms that are not uniformly understood. These include: a) "preserve," b) "naturally functioning," c) "disturbed," d) "developed or subdivided", and "restored." While these terms may seem clear, the interpretation of the terms has varied in past threshold evaluations"* (quoted from TRPA, 2015). In addition, disturbed land in non-urban areas may be an "easier" and less expensive target compared to developed lands. The goals are expressed in *percentage of the total area* in each of the two categories, each with very different total areas.

In particular, the categorization of restoration goals and restoration project in "undeveloped" and "disturbed" lands seems very confusing. From Appendix E: "SEZ Restoration Projects in the Lake Tahoe Basin from 1980-2015" (TRPA, 2015), the restoration of the gravel pit area along Blackwood Creek is listed as representing a non-urban area, but it was not clear if it was counted toward the goal of "*restoring all SEZ's in undeveloped, un-subdivided lands"* or if it was counted toward the goal of *restoring 25 percent of the SEZ lands that have been identified as disturbed, developed, or subdivided.* Clearly, the gravel pit was disturbed land but not "developed or subdivided" and was listed under "non-urban" lands. The 2015 Threshold Evaluation Report had a substantial discussion of the problems in classifying the goals and pointed out inconsistencies among prior Threshold reports (e.g. the 2006 report) in classifying the restoration projects. Regardless of the classification, the restoration of the disturbed areas along Blackwood Creek should be high priority since Blackwood Creek represents one of the major loads of total P and sediment (Appendices, TRPA, 2015).

In the 2015 Threshold Evaluation Report (TRPA, 2015)., the in the Soil Conservation section, the following summary was made: *"Recommendations for improvement of the monitoring program included a process for updating critical benchmarks for the current threshold standards, as well as the need for a better benchmark, based on best available science, for the Stream Environmental Zones."*

Timeliness of goals

The goal of 25% restoration of was ambitious for the time but that goal was set 36 years ago. It may be argued that further progress would result in further benefits to the slowing of the eutrophication of Lake Tahoe and to the environment of the SEZ themselves. (TRPA 1978), As a reply to one reviewer of the 2015 Threshold Evaluation Report, the original limitation to 25% may have been revealed in the following statement from a 1978 report "*The cost of restoring all SEZ to their natural state would be cost prohibitive. This solution should only be applied in limited situations where benefits received would also be substantial*." (Quoted from "Responses to Peer Reviews" of 2015 Threshold Evaluation Report). It could be argued that attainment of that goal would indicate that further improvement would not be prohibitively expensive.

In particular, a probable growth of impervious surface after 1982 may detract from the goal of 25% restoration in developed and subdivided areas. For example, in the South Lake Tahoe Basin area covered by the study of Raumann and Cablk (2008), the rate of conversion of pervious to impervious surface was 4.1 ha per year. However the impervious cover declined slightly 2010 and 2015 (TRPA, 2015). Some impervious cover outside of SEZ's probably drain into SEZ's. The impervious cover remains "considerably below target" in the land class 1b, very poorly drained land, and hence, SEZ (TRPA, 2015). On the other hand, developed and subdivided land is also the most expensive and sociologically difficult to restore. If we accept the values expressed in the original thresholds, then it may be argued that continuing to express those same values would require updating the restoration goals.

Subdivision of restoration goals by type and location of SEZ

Location or land use category

The original resolution adopted in 1982 (TRPA, 1982) established two categories based on location (or land use status). The 2015 Threshold Evaluation Report contains a detailed discussion of the ambiguities that have arisen particularly in defining (a) those in *undeveloped, un-subdivided lands,* versus (b) those on *disturbed, developed, or subdivided lands.* The 2015 Threshold Evaluation Report on pages 5-16 and 5-21 outline the changes classifying what lands fit in these categories between the 2006 and 2015 reports, and a discussion of the interpretation based on what might be called "legal arguments" and "practical" concerns. These arguments are so central to this discussion that they are included in Appendix 1 of this report. There is parallel classification for restoration projects in the Appendix as "urban", adjacent to urban areas, or non-urban, (and unknown for some prior to 1996). A table or system for translating these categories into commonly understood categories such as urban, high density suburban, low density suburban, ski slopes, forest service roads and non-urban disturbed (gravel pits, graded, filled, severely eroded) would help bridge both scientific and public understanding of the goals. We have already noted the critical distinction in non-urban "disturbed' land vs. urban area.

The 2015 Threshold Evaluation Report also noted a decrease in the recent rate of restoration in urban SEZ: "More recently (2010 to 2014), the average restoration rate for urban SEZ was 11 acres per year, equivalent to a restoration rate 0.49 percent (per year, sic.)". This rate was considerably below the average rate for the period between 1980 and 2014 which was 20 acres per year. Perhaps this may reflect financial problems associated with the 2008 recession, or that the "easier" or less expensive urban restoration targets had already been restored. The attainment of the 25% goal seems heavily dependent on the Upper Truckee/Trout Creek restoration project. There may be a question of what proportions of that project would be classified as "restoration" versus "enhancement" (as defined by EIP Project Tracker, 2018).

It seems clear that by creating a separate category for those on *disturbed, developed, or subdivided lands,* that part of the original intent was to assure that urban and subdivided lands *would* be subject to restoration. If the standard that did not require restoration of this category, it would be easier and cheaper to concentrate all restoration efforts on non-urban areas. As such, the creation of this category based on land use or location of SEZ was very important in encouraging the more expensive restoration of SEZ in urban areas.

The scientific importance of subdividing restoration goals is important given that urban use and impervious cover within urban zones have been shown to contribute disproportionate amounts of sediment and nutrients on an areal basis (Rios et al., 2015). In addition, a larger proportion of urban runoff is biologically available compared to LTMP creeks (Ferguson and Qualls, 2005). An elemental analysis of 16 years of accumulation of sediment and organic matter in the Tahoe City Wetland Treatment System wetland showed that most of the sediment did not originate from erosion of surrounding upland soils, but from either the alluvial Tahoe Series soil, that occurred in the capability class 1b of the 22 Ha watershed, or traction sand that was also collected from similar alluvial soils (Qualls and Heyvaert, 2017). The sediment yields on a watershed basis were *far* higher that from LTMP creeks. This indicates the importance of urban runoff and drainage in urban SEZ soils, and also the possible benefits in resorting them (or providing artificial wetlands for the runoff).

Need for a list of all SEZ that are in need of restoration.

In order to evaluate the goals of restoration of any of the categories it would be helpful to have a survey and map of all SEZ in the entire basin that are degraded and would benefit from restoration. For urban areas, the SEZ are being mapped in detail and it will be relatively simple to tell which developed areas are in SEZ and where SEZ are under impervious cover (but with limited resolution along many boundaries). However, the degradation status of all SEZ areas in urban areas would be helpful in establishing goals. A map of completed and planned restoration projects appeared in the 2015 Threshold Evaluation Report, but it did not include areas in need of restoration.

Historic SEZ that are now developed are not included in current accounting for restoration goals. These mapping efforts for defining these will also contribute to the list of SEZ in need of restoration. Many of these may lie in urban areas. These may include: areas filled for development and original stream courses that have been channelized or diverted.

For the original goal "*restore all disturbed SEZ lands in undeveloped, un-subdivided lands*", it would again be necessary to have survey and map showing all SEZ in the entire basin that are degraded and would benefit from restoration. In the 2015 Threshold Evaluation Report, there was a discussion of why there was not a target set for this goal (https://thresholds.laketahoeinfo.org/ThresholdIndicator/InfoSheet/134#monitoring). Many of these are likely to lie on USFS land. The history of logging, grazing, channelization and damming (Raumann and

Cablk, 2008) make it likely that there are many hectares of SEZ that would benefit from restoration and enhancement. The California Rapid Assessment Method for streams ("CRAM", Collins et al., 2008; Collins et al., 2013) would be a method for deciding what areas of SEZ would benefit from restoration. The method would give a quantitative evaluation of the condition of the various reaches of SEZ and provide a more scientifically based rationale for the need for restoration. However, a ground based evaluation of the entire LTBMU would take considerable effort as has already been done for the Third Creek and Upper Truckee watersheds (Collins et al. 2013).

Use of area as a measure for setting goals for restoration

Given a system of subdividing SEZ and assigning priorities (or relative benefits) to each category, the area within each is still the best measure for evaluation. Many of the most fundamental ecological measures are based on area (e.g. watershed sediment yield, canopy cover), net ecosystem productivity. In addition, many measures of attainment of standards are based on area. Many measurements of economic value of ecological function are also based on area (e.g. value of wetlands as water treatment systems, in units of dollars per Ha, (Mitsch and Gosselink, 2015). The differing values and benefits can be accounted for by categorization and prioritization.

Subdivision of restoration goals by type of SEZ

The report by Roby et al. (2015) outlined a proposed system of categories of SEZ for the Lake Tahoe Basin and provided a comparison of the benefits and deficiencies of several systems. They considered the Cowardin system (Cowardin, 1992), the USACE Hydrogeomorphic (HGM) Classification (reviewed in Mitsch and Gosselink, 2015), California Aquatic Resource Classification System (CARCS, 2013), and "*A Field Key to Meadow Hydrogeomorphic Types for the Sierra Nevada and Southern Cascade Ranges in California*" (Weixelman *et al*. 2011) and site descriptions included in the NRCS soil survey as "*General Site Descriptions*" for the Tahoe Basin (USDA-NRCS, 2007). The system proposed by Roby et al. (2015) is essentially the CARCS (CARCS, 2013) system, with one minor difference; smaller ponds would be included in the lacustrine category (see Figure 1). The CARCS system was in turn a hybrid of the Cowardin and hydrogeomorphic system. However the CARCS does include "meadows" as a more regional name for *non-inundated,* high water table herbaceous wetlands. Meadows are specifically mentioned in TRPA regulations (TRPA, 1984). The system proposed in Roby et al. (2015) also includes slope and seep wetlands derived from the hydrogeomorphic system. It also includes *fens* as a special type of slope or depressional wetland. Thus, it is adapted to local Lake Tahoe basin conditions and previous regulatory language.

The TRPA thresholds (TRPA, 2015) place value on all types of meadows, including both dry and wet meadows. For purposes of defining which of these fall under the restoration goals for SEZ specifically, it might be useful to distinguish hydrologic indicators of wet meadows as distinguished from dry meadows. A study by Loheide and Gorelick (2007) established a general graph of water table depths versus date in the growing season for meadows in the Northern Sierra Nevada (see Figure 2). From this diagram a rule of thumb would be that "wet meadow" and "dominantly wet meadow vegetation" has a depth to the water table of 1 meter or less until about July 4th. A more detailed system was created for the USFS by Weixelman et al. (2011), based on hydric soil indicators and dominant species.

The "riverine" classification is found both in the Cowardin system and the hydrogeomorphic system (see tables 13-3 and 13-4 in Mitsch and Gosselink (2015) but the Cowardin system considers only wetlands actually located in a channel as "riverine", while the hydrogeomorphic system includes the riparian zone. Conceptually, a useful and comprehensive functional categorization of stream courses in the Lake Tahoe Basin might be the following:

1. Intermittent streams,
2. Permanent streams located in erosional zones (located in steeply sloped, V shaped drainages), and
3. Permanent streams located in depositional zones (with a clear floodplain).

The ecological distinction between numbers one and two above would be the potential for sediment to be deposited on floodplains, the cross-sectional width of groundwater exchange with a hyporheic zone, and the width of vegetation dependent on a shallow groundwater table. These would also be easy to map with GIS using the cross section of mapped contours, (floodplain versus V-shaped cross sections), or LIDAR data. The ephemeral reaches could simply be mapped from existing USGS maps. The CARCS system (CARCS, 2013) comes close to this categorization using the following categories:

1. Unconfined riverine: rivers or streams with a floodplain less than twice the width at bank-full flow.
2. Confined riverine: rivers or streams with a floodplain more than twice the width at bank-full flow.

The text of the Spatial Informatics Group document (Roby et al., 2015), does include intermittent streams in the category of "Confined riverine".

Extent of SEZ along stream courses

In the original definitions of the SEZ in the Lake Tahoe Basin, it is clear that the SEZ along streams includes the riparian zone, not just the area "frequently flooded" by the stream. The definition below specifies "riparian areas" in addition to streams and supplements the definition to include "other areas expressing the influence of surface or *groundwater* (italics added by authors).

"Generally an area that owes its biological and physical characteristics to the presence of surface or ground water." This definition includes "perennial, intermittent, and ephemeral streams; wet meadows, marshes, and other wetlands; riparian areas, beaches, and other areas expressing the presence or influence of surface or ground water" (cited from TRPA, 2015).

Although the term riparian zone has a clear general definition (e.g. Mitsch and Gosselink, 2015) it needs more precise definition for regulatory purposes. These guidelines used for the Parcel Evaluation System (TRPA, 2013) are listed in Appendix 3. Jurisdictional wetlands, as defined by the USACE, NRCS, and USFWS (US Army Corps of Engineers, 1987), are clearly more restrictive than a "riparian zone" in the requirements of vegetation, hydric soil indicators and groundwater level.

In riparian areas that are not excessively disturbed, vegetation is widely used as an indication of long term groundwater levels using certain indicator species. In the criteria for delineating SEZ, the presence of "primary riparian vegetation" is sufficient to classify the area as SEZ (Appendix 3), and such woody species as aspen, black cottonwood creek dogwood, mountain alder, pacific willow, Scouler's willow are listed as "primary riparian vegetation. The list of species includes plants with a wetland indicator status of "facultative" such as black cottonwood *Populus balsamifera* ssp. *trichocarpa* (USFWS classification) and so, are not overly restrictive. For example, the habitat of the black cottonwood is listed in the USDA plants database as follows "Black cottonwood grows on alluvial sites, riparian habitats, and moist woods on mountain slopes, at elevations of 0-2750) meters."

For purposes of creating a priority system for restoration of SEZ, the extent of the riparian zone that is classified as SEZ is important. In the description of SEZ types derived from the CARCS system described in Roby et al. (2015) the classification of SEZ along, but not within, riverine confined or unconfined types is not clear. They might be considered as "forested SEZ" or "meadows" depending on whether the riparian vegetation is woody or herbaceous. Nevertheless, the TRPA parcel identification system provides for a “setback” zone of 15 to 60 feet along the boundary of the SEZ (see Appendix 4). Thus there is some protection for narrow riparian areas built into the “setbacks”. Many states have riparian buffer zone regulations that have a given width of buffer along stream courses, most oriented toward logging impacts and protecting streams from direct radiation (see Topic Brief A).

Extent of SEZ along stream courses

In mitigation for permits under section 404 of the Clean Water Act, the concept of requiring that replacement of wetlands to be in the same watershed and of a similar function is widely accepted (Mitsch and Gosselink, 2015). The language from the federal “General compensatory mitigation requirements” in 33 CFR 332.3 is as follows:

“In general, the required <u>compensatory mitigation</u> should be located within the same <u>watershed</u> as the <u>impact</u> site, and should be located where it is most likely to successfully replace lost <u>functions</u> and <u>services</u>, taking into account such <u>watershed</u> scale features as aquatic habitat diversity, habitat connectivity, relationships to hydrologic sources (including the availability of water rights), trends in land use, ecological benefits, and compatibility with adjacent land uses.” (33 CFR 33.3)

It also seems reasonable that the ideas of “in kind” mitigation should also apply to mitigation for development of wetlands in SEZ in the Lake Tahoe Basin. Since there are 64 stream watersheds in the Lake Tahoe Basin, it might be reasonable to require mitigation to occur in adjacent or nearby watersheds. A grouping into nine sets of adjacent watersheds was used by Sahoo et al. (2013). In terms of location, “in kind mitigation” would be also more consistent if it required that mitigation would also be done in the same land use categories that would be consistent with the original subdivision of SEZ into (a) “*disturbed SEZ lands in undeveloped, un-subdivided lands”* and (b) *“SEZ lands that have been identified as disturbed, developed, or subdivided”*. This concept would be compatible with the phrases “trends in *land use*, ecological benefits, and *compatibility with adjacent land uses*.” in the federal General compensatory mitigation requirements in 33 CFR 332.3 (italics added by authors).

A further extension of the “in kind” mitigation concepts would be to require mitigation (including restoration or enhancement) in the form of similar types of SEZ. In the case of urban or subdivided areas that have already been disturbed, this may require knowledge of what types of wetlands normally lie on similar soil types (consulting the NRCS soil maps and their ecological descriptions). It may not be necessary in all cases to subdivide the types of wetlands listed in Figure 1, but more general groupings might be used. As an example, such as allowing mitigation for a parcel on “very poorly drained soils”, which would be capability class 1b which had been forested wetlands, to be mitigated with restoration of forested wetlands in either a depressional area or an area lying along an unconfined riverine wetland.

If mitigation projects are designed to match the land use categories, watersheds, and general SEZ types listed in Figure 1, then the *<u>area required</u>* in the mitigation agreement would be an appropriate measure of restoration. If the “in kind” mitigation concepts are followed, a relative prioritization scheme would not be necessary for restoration projects for mitigation.

A method of establishing the relative benefits or values of SEZ by type and location

A “lake centered approach”

The first method for establishing the relative benefits and values of SEZ will be called “a Lake centered” system. This system would place the health of Lake Tahoe as the most important value. Prevention of eutrophication, clarity and health of the fishery would be central values. Using these central values the most important measure of the relative benefits of restoration in the various watersheds might be the annual load total phosphorus discharge into Lake Tahoe from the major tributaries. The rationale for this measure is that phosphorus is the chief limiting nutrient in Lake Tahoe. Suspended fine particles are also important in determining the clarity of Lake Tahoe, but over 80% of the total P load is in the particulate fraction (Sahoo et al., 2013), so the two measures are correlated. In a study of that estimated loads of major nutrients and sediment from the 10 major watersheds in the Lake Tahoe, four watersheds contributed 83% of the total P load from 10 monitored creeks: the Upper Truckee River, Blackwood Creek, Ward Creek, and Trout Creek. Of the modelled total P load, 18% came from urban sources and 47% from non-urban sources (Sahoo et al., 2013). Stream channel erosion was estimated to account for 27% of the suspended fine sediment (< 63 um diameter). From the loading estimates it is difficult to assign an estimate to all of the area included in SEZ since only streambank erosion was estimated separately and did not include estimates from higher order streambanks and other sources in the SEZ. Thus a concentration on restoration in the four principal watersheds that contribute the majority of total P loading may be beneficial to the total load of P flowing into the lake, but it would be difficult to assign relative values to restoration within the SEZ as opposed to uplands, and urban runoff that by-passes the SEZ.

In order to have a more exact quantification of the benefits of SEZ restoration, it would be necessary to conduct a more specific survey of total P concentrations in various portions of the watershed along specific reaches upstream and in ditches that may feed into streams. This may allow a more exact attribution of the deposition of sediment in SEZ and any contributions of erosion from SEZ as opposed to the rest of the watersheds. A model for such studies, at least for sediment, was done in the watersheds of Blackwood, General, Edgewood and General Creeks by the USGS in 1983-84 (Nolan and Hill, 1991). That study was particularly useful for distinguishing sediment sources from SEZ versus surrounding slopes since they collected samples from several reaches and tributaries in each watershed, placed erosion traps on hillslopes, and measured the volumes of sediment in banks and bars. Blackwood Creek had by far the greatest sediment yield (kg/ha) and the greatest sources were streambanks and bedload, not the surrounding uplands. A key finding in the role of riparian vegetation in stabilizing streambanks and the potential measures for restoration is in the following summary quoted from Nolan and Hill (1991):

"The main channels of the larger and wetter westside basins of Blackwood and General Creeks are too deep to be stabilized by riparian thickets of willow and alder. Bank heights along these channels are often in excess of 2 m, and roots of most riparian species penetrate only a meter or less. Bank heights in Edgewood and Logan House Creeks rarely exceed 1 m."

Also, conducting "before and after" studies of reaches subject to restoration (such as along Blackwood Creek) would be beneficial. One such study was done on Blackwood Creek in the reach that had been restored after having been subjected to channelization and gravel mining in the past. A survey after the restoration found that a net of 987 m^3 of sediment had been deposited in 2 years, but only 9% of that was in the silt and clay fractions (Immeker, 2012).

Habitat in streams that contributes to the health of fish populations may also be given a relative importance in the "lake centered system". Restoration effort in stream channels that improve the substrate in streams (see the diagram for the conceptual model), algal production, and aquatic invertebrate populations would also have a relative benefit.

Other approaches to establishing the benefits of SEZ's and restoration

One approach to quantifying the benefits of wetlands has been the economic evaluation in terms of dollars. The most widely cited values are \$25,681 ha^{-1} y^{-1} for inland swamps and floodplains, and \$25,681 ha^{-1} y^{-1} for lakes and rivers for ecosystem goods and services, in 2011 dollars (Costanza et al., 2014). These values are aggregated from a large number of studies. There are few problems in applying these values to SEZ in Lake Tahoe. First, most of the estimates are derived from replacement values (e.g. the cost to build wastewater treatment plants to achieve the same water quality goals or dams to mimic the effect of wetlands on flooding). Four aspects of ecological value that environmental economists recognize are: *Use value* (e.g. recreation fishing), *Social value* (water quality, flood protection), *option value* (options remain open for future use), and *existence value* (e.g. biodiversity) (Mitsch and Gosselink, 2015). The economic valuations, particularly those based on replacement value like those of Costanza et al. (2014) tend to address only *use value* and *social value*. Another problem with applying these values to the Lake Tahoe basin is that most values were based on the costs of wastewater treatment to standards too low for the preservation of an ultra-oligotrophic lake like Lake Tahoe, or the costs of small dams in rural agricultural watersheds where land prices are lower. A third problem with their application to SEZ is that they are not estimated separately for the various types of SEZ found in the Lake Tahoe Basin.

A great advantage of the values expressed in the "Thesholds" for the Lake Tahoe Basin is that they explicitly recognize use value (e.g. recreation), social value (e.g. water quality, option value, and especially existence value (e.g. preservation of uncommon communities, scenic resources). Another value that has been added into the conceptual model (Fig. 1, Introduction to the Conceptual Model) is carbon sequestration, a social value. It may be possible to compile a set of economic valuations for various benefits specific to the Lake Tahoe basin, but it would take research (such as the costs of BMP, alum flocculation, etc.) in the Tahoe Basin as an estimate of replacement costs for sediment and P removal by SEZ.

Relative valuation: Habitat evaluation procedures and Hydrogeomorphic Analysis

Some federal agencies and many state agencies have adopted various ways of comparing the relative function of streams and wetlands to some standard or evaluating the present state, restored state or reference state of streams and wetlands. Several of these have been summarized and compared in Mitsch and Gosselink (2015). These methods develop a list of functions or attributes that have some are hydrologic, geomorphic, ecological or habitat quality properties. These might be expressed in the Conceptual model in Figure 1 (Introduction to the Conceptual Model) as *attributes* of the state variables (for example % cover of canopy). These methods develop a "scorecard" which has actual or relative values that express the degree to which they are properly functioning. The hydrogeomorphic analysis (Rheinhardt et al. (1997) compares these "scores" to reference wetlands that are typical for a relatively healthy example of a specific type of wetland in the region. The California Rapid Assesment Method (Collins et al., 2008) for wetlands seems to closely resemble the hydrogeomorphic analysis and it has been applied in the Lake Tahoe basin (Collins et al. 2013).

A key concept in the hydrogeomorphic analysis is the comparison to a reference site. Then the condition is assessed as a proportion of the conditions at the reference site. There were no reference sites established in the Lake Tahoe Basin itself for the assessment of Collins et al. (2013), but there were comparisons to sites in other locations in the Sierra Nevada. A key priority in using such a system extensively in the Lake Tahoe Basin would be to establish reference sites for each type of wetland listed in Figure 1, especially for confined riverine SEZ and forested wetlands adjacent to confined riverine SEZ.

Approaches for establishing relative priorities for restoration

The hydrogeomorphic analysis also explicitly designed a method to compare a wetland being destroyed to the likely functions of restoration alternatives. For application to the Lake Tahoe Basin, the eventual state of the restored SEZ would require extrapolation into the future and comparison to a “reference SEZ”. As a way to generate one aggregate index of the function or each wetland Rheinhardt et al. (1997) designed a hydrologic function index that was just an average of individual indices of each function. That approach involves equating functions that might be judged as having varying degree of importance.

The extension of a variation of the hydrogeomorphic analysis to issue #2 in the Introduction: (“Subdivision of restoration goals by type and location of SEZ”) would require two more quantitative comparisons. These are posed below as questions:

(a) How do we quantitatively compare the benefits of SEZ for different values (as expressed in the Thresholds)?

(b) How do we quantitatively compare the benefits from each different type of SEZ?

As a more specific example of question (a): are the benefits to water quality (as measured by reduction in sediment load and total P load) more important than the benefits of substrate improvement to fisheries? A more specific example of question (b): are herbaceous wetlands more beneficial to water quality than unconfined riverine SEZ?

A quantitative way to approach both questions (a) and (b) simultaneously is outlined below. It begins with a list of all of the values derived from the thresholds listed in the conceptual model.

Step 1. Assign a relative weight (i_v) to each value such that the sum of all equals 1.0.

$$i_{v1} + i_{v2} + i_{v3} + \ldots i_{vn} = 1.0$$

This step requires making some subjective decisions about the importance of SEZ as a whole in each category of values (water quality, etc.). This step is illustrated in Table 1 where only the column “Overall weight for each value” is filled in, and all values are considered equal in this example.

.**Step 2.** The second step is to assign a relative weight (importance) to each type of SEZ *within* each category of values such that the sum for weights within each category of values equals 1.0

$$i_{sez\ 1} + i_{se\ z2} + i_{sez\ 3} + \ldots i_{sez\ n} = 1.0$$

The comparison is necessary in assigning priorities for restoration when there are choices of different types of SEZ. For example confined riverine SEZ with steep slopes are probably less important than unconfined SEZ near the lake for fish habitat. This step is illustrated in Table 2 in which each row of the matrix contains a relative weight (importance) to each type of SEZ *within* each category of values, and all SEZ are considered equal in this example. These relative weights are all based on a *benefit per hectare* of each SEZ type so that SEZ with less area in the basin are not excluded from priorities.

Step 3. The final step is to calculate the relative weight for each SEZ when all categories of values are considered.

$$i_{sezn\ vn} = i_{vn} * i_{sez\ n}$$

This step is illustrated in Table 3, in which each cell in the matrix contains $i_{sezn\ vn}$, indicating a relative weight (importance) to each type of SEZ *over all* categories of values.

Step 4. Calculate the total relative weight for each type of SEZ over all categories of values. The sum of all

$i_{sezn\ vn}$ values for each type of SEZ is calculated on the bottom row of the matrix. The value indicates the final relative priority for restoration of each type of SEZ. This step is illustrated in Table 3 in the bottom row "Sum for each SEZ type".

The sum for each SEZ type is meant to indicate the relative priority for restoration of each type of SEZ given its importance in maintaining the values expressed in the thresholds (See conceptual model). Some categories of SEZ might be excluded from the worksheet if it is determined that they would not be subjects for restoration, or they could simply be skipped in decision making. Lakes and ponds were not included in the matrix because they may be considered for preservation, but not in need of restoration.

An Excel worksheet was developed to aid in the calculation of the matrix of relative weights. It will be attached as a separate Appendix (Appendix 5) to this report. It also incorporates a "scorecard" matrix that allows a score on a scale of 0-5 for the relative importance of each type of SEZ within each category of value and then automatically scales the coefficients to equal 1 in the matrix.

Integrating area, time period, and location (or land use) into the system for prioritization

The prioritization system for SEZ types above is meant to be based on benefits *per unit area* (hectare). The highest priority SEZ under the prioritization system should not "monopolize" all restoration efforts until it is completely restored. A system to assure that other types receive some effort is to assign goals for the number of hectare per unit time based on the prioritization system. For example, given a 5 year plan for restoration, one type of SEZ (type A) that has twice the priority as type B would merit twice the number of hectares of restoration as type B. Given that some types of SEZ (such as unconfined riverine SEZ) have more area than others (such as fens), the prioritization might be allocated on a basis of % of total area of a given type of SEZ. Likewise, during each time period (e.g. the 5 years between threshold evaluations) the goals for each type of SEZ would be modified based on success. In this system large restoration projects would be favored over small restoration projects only in proportion to the area that is restored within the type of each SEZ.

Location in the Lake Tahoe Basin may be incorporated into the prioritization system in a relatively simple way that is consistent with existing TRPA ordinances. Currently the lands in the basin are considered in one of two categories of "land use" (the term applied by the authors) (a) *undeveloped, un-subdivided lands, and (b) disturbed, developed, or subdivided.* Given that the ambiguity in the term "disturbed" can be settled, and that new goals for further restoration of "*disturbed, developed, or subdivided"* are set (e.g. an additional 25%), then the prioritization system for types of SEZ can simply be applied separately for each category of land use. This separate application has several advantages:

(1) It is consistent with current ordinances,

(2) It enables the different types of SEZ common in developed lands (e.g. riverine unconfined SEZ) to be prioritized separately from the types more common in undeveloped land (e.g. riverine confined SEZ or fens).
(3) It continues to assure that restoration of developed lands continues and is not discontinued because of higher costs.
(4) SEZ near the shore of Lake Tahoe continue to be restored (given that SEZ close to the lake may have greater benefit in intercepting sediment and urban runoff.

In terms of restoration resulting from mitigation, following the guidelines for “in kind” mitigation outlines in a previous section, would ensure that the locations of restoration projects be equitably located among different watersheds and proximity to urban areas.

Recommendations: A step by step procedure for establishing priorities for restoration of SEZ.

1. Clarify how restoration of disturbed SEZ lands in *undeveloped, un-subdivided lands* will be counted in the restoration goals for *undeveloped, un-subdivided lands,* vs. those in *developed, or subdivided lands.*
2. Develop new goals for restoration of *developed, or subdivided lands.*
3. Continue to distinguish between goals for *undeveloped, un-subdivided lands*, and *developed, or subdivided* lands so that restoration of developed lands continues to be pursued despite the greater cost.
4. Continue developing a comprehensive map of SEZ lands in the basin including (a) SEZ along streamcourses too narrow to be included in soil maps (by appending the SIG map units along riparian zones less than about 100 m. wide) and (b) appending meadows mapped by the USFS that are not included in the current maps.
5. Include historic SEZ in restoration goals.
6. Establish a set of reference sites for each type of SEZ that serve as a healthy, natural example of each type.
7. Make a comprehensive survey SEZ land in need of restoration by using existing surveys, and adding surveys based on the CRAM system and compare functions to the reference sites.
8. Establish a procedure for restoration projects that result from mitigation to assure that they are “in kind” (in the same or nearby watersheds, and are of the same type of SEZ). In that way, they will be compatible with other priorities for restoration (see next item).
9. Establish a procedure for restoration of each type of SEZ given its importance in maintaining the values expressed in the thresholds (See conceptual model).

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Figure 1. Comparison of the CARCS and recommended SIG classification systems. Reproduced from Table 7 and Figure 3 in Roby et al. (2015).

Table 7. California Aquatic Resource Classification (CARCS) major classes, classes and types

Major Class	Class	Type
Open Water	Lacustrine	
	Riverine	Confined
		Unconfined
	Estuarine	Lagoon/Dune Strand
		Bar Built Estuary
		Open Embayment
	Marine	Inter-tidal
		Subtidal
Wetland	Depressional	Depression, Other
		Vernal Pool Complex
		Playa
	Lacustrine	
	Slope	Wet Meadow
		Forested Slope
		Slope, Other
	Riverine	Confined
		Unconfined
	Estuarine	Lagoon/Dune Strand
		Bar built Estuary

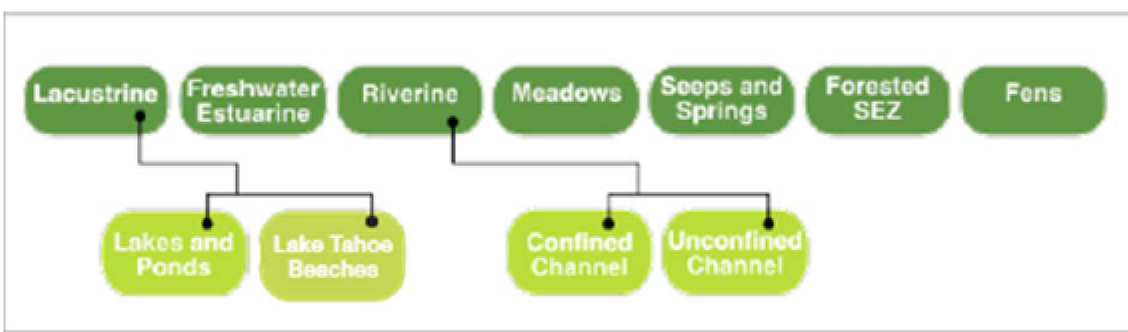

Figure 3. Recommended Tahoe Basin Stream Environment Zone Classification Scheme

Figure 2. Hydrologic relationships between wet meadow, dominantly wet meadow, and dominantly xeric meadows in Plumas National Forest in the northern Sierra Nevada. Taken from Loheide and Gorelick (2007).

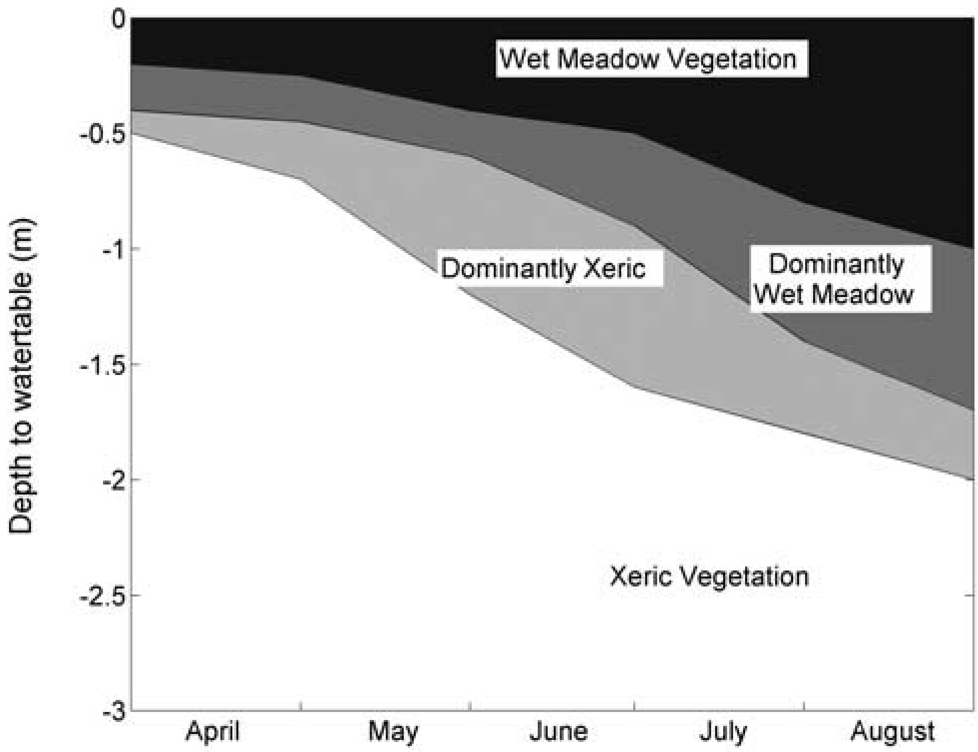

Table 1. Worksheet for assigning relative priorities for restoration of each type of SEZ. Relative importance values are entered on a scale of 0-5 with 5 being "very important". Steps 1-3 for entering relative weights are indicated below. The scaled results appear in Table 2. *The numbers in this Table are only to illustrate the use of the worksheet.*

Step 1. Assign a relative importance of each "value" in the context of the contributions of SEZ's overall (in blue column) on a scale of 0-5

Step 2. For each value assign a relative importance of each type of SEZ in contributing to each value (cells B4 to J4, then B5 to J5, etc.)

Step 3. The relative priorites for each SEZ appear in row 24 such that the sum for all SEZ types = 1.00 (in yellow row)

Values	Riverine unconfined SEZ	Riverine confined SEZ	Other forested SEZ	Other herbaceous wetlands	Fens	Seeps, springs	Wet Meadows	Freshwater estuarine	Beaches	Overall weight for each value	Sum of weights for each type
Water quality in streams, lakes, wetlands	5	4	4	5	0	1	2	5	1	5	27
Species of concern	1	1	1	1	5	2	3	1	5	2	20
Preservation of functional wetlands, streams, floodplains, uncommon communities	5	4	5	5	5	2	4	5	2	5	37
Sustainable recreation (fisheries, access, hiking)	5	2	2	1	1	1	3	0	5	2	20
Public health and safety	4	1	5	5	1	1	4	0	1	1	22
Resilient forests	3	3	3	0	0	1	0	0	0	2	10
Carbon Sequestration/Greenhouse gas mitigation	2	1	1	5	5	1	5	3	0	5	23
Sum for each SEZ type	25	16	21	22	17	9	21	14	14	22	

Table 2. **.** Matrix containing the scaled relative weight for each SEZ type and value. The relative priority for restoration is indicated in the row highlighted in yellow. It is scaled so that the sum for all SEZ types = 1.0. *The numbers in this Table are only to illustrate the use of the worksheet.*

Matrix for calculations of relative coefficients. Do not enter anything below this line.											
Values	**Riverine unconfined SEZ**	**Riverine unconfined SEZ**	**Other forested SEZ**	**Other herbaceous wetlands**	**Fens**	**Seeps, springs**	**Wet Meadows**	**Freshwater estuarine**	**Beaches**	**Overall weight for each value**	**Sum of weights for each type**
Water quality in streams, lakes, wetlands	**0.05**	**0.06**	**0.04**	**0.05**	**0.00**	**0.03**	**0.02**	**0.08**	**0.02**	0.227	1.0
Species of concern	**0.00**	**0.01**	**0.00**	**0.00**	**0.03**	**0.02**	**0.01**	**0.01**	**0.03**	0.091	1.0
Preservation of functional wetlands, streams, floodplains, uncommon communities	**0.05**	**0.06**	**0.05**	**0.05**	**0.07**	**0.05**	**0.04**	**0.08**	**0.03**	0.227	1.0
Sustainable recreation (fisheries, access, hiking)	**0.02**	**0.01**	**0.01**	**0.00**	**0.01**	**0.01**	**0.01**	**0.00**	**0.03**	0.091	1.0
Public health and safety	**0.01**	**0.00**	**0.01**	**0.01**	**0.00**	**0.01**	**0.01**	**0.00**	**0.00**	0.045	1.0
Resilient forests	**0.01**	**0.02**	**0.01**	**0.00**	**0.00**	**0.01**	**0.00**	**0.00**	**0.00**	0.091	1.0
Carbon Sequestration/Greenhouse gas mitigation	**0.02**	**0.01**	**0.01**	**0.05**	**0.07**	**0.03**	**0.05**	**0.05**	**0.00**	0.227	1.0
Sum for each SEZ type	**0.149**	**0.165**	**0.145**	**0.174**	**0.168**	**0.146**	**0.154**	**0.218**	**0.117**	1.000	

Appendix 1: Rationale for threshold evaluation of restoration of disturbed, developed, or subdivided lands. Quoted directly from the 2015 Threshold Evaluation Report.

Rationale - Restore 25 percent of the SEZ lands that have been identified as disturbed, developed or subdivided. This component of the standard is a numerical standard. Over five threshold evaluation reports and three decades it has not been consistently quantified or evaluated. The last two threshold evaluation reports (2006 and 2011) provided different interpretations of "disturbed, developed, or subdivided" with implications for which SEZ restoration projects contribute toward attainment of the threshold standard (TRPA, 2012c, 2007). The 2006 Threshold Evaluation Report suggests a narrower reading of the standard, and that SEZ restoration projects on "un-subdivided lands should be excluded from the tally of projects that contribute towards the objective of restoring 25 percent of the SEZ lands that have been identified as disturbed, developed, or subdivided (TRPA, 2007)." The 2011 Threshold Evaluation Report suggests that the criteria used in 2006 Threshold Evaluation Report imposed an unstated requirement that restored SEZ be located inside the urban boundary in order to count towards achievement of the standard. The 2011 Threshold Evaluation Report suggests a broader reading of the standard: "It seems reasonable to conclude that the 25 percent threshold standard goal does not have to be attained exclusively within the 'urban areas,' but does need to be attained adjacent to, or associated with, disturbed, developed, or subdivided lands in the Region (TRPA, 2012c)." There is little evidence within the standard to support the application of a strict location-based criteria where restoration of 25 percent of the SEZ must occur. Such a reading seems to be based on an improper juxtaposition of the two clauses in the standard that treats restoration of "all disturbed SEZ lands in undeveloped, un-subdivided lands," and "restore 25 percent of the SEZ lands that have been identified as disturbed, developed, or subdivided" as mutually exclusive objectives. Treating the standards as mutually exclusive rather than supporting seems to have its origin in the 2006 Threshold Evaluation Report (TRPA, 2007). Earlier threshold evaluation reports treated the two objectives as concordant and self-reinforcing rather than mutually exclusive (TRPA, 2001, 1996, 1991). While the 2006 and 2011 Threshold Evaluation Reports read the standard differently, no accompanying adjustment of the numeric target was made to accommodate the new spatial criteria. The total amount of SEZ inside urban boundaries is estimated to be 3,496 acres (including beaches and the Tahoe Keys), significantly less than the 4,400 acres of disturbed developed or subdivided SEZ that has historically been used as the benchmark for standard assessment. If all SEZ inside urban boundaries was disturbed or developed, then the restoration of 25 percent would require restoration of 874 acres. The first Threshold Evaluation Report (1991) estimated that there were 4,400 acres of "disturbed, developed, or subdivided" lands in the basin and the basis for target attainment (1,100 acres) has historically been calculated using this number. Of this amount, it was estimated 2,500 acres were developed or disturbed and that 1,900 acres were subdivided but not developed and still retained their natural hydrologic regime (TRPA, 1988). This baseline for target attainment can be found in the 1988 208 plan for the basin, which provided a project roadmap for attainment of the 25 percent restoration standard. To attain the 1,100-acre target, the 208 plan identified 452 acres of restoration projects inside the urban boundary and an additional 701 acres of restoration opportunity outside urban areas (TRPA, 1988). The report establishing the thresholds in 1982 suggested that there were 4,376 acres of developed or subdivided SEZ that could be preserved or restored to their natural state, which also suggests that restoration would not be required on all 4,376 acres because some could simply be preserved (TRPA, 1982).

Appendix 2. Definitions from EIP tracker statement
(https://eip.laketahoeinfo.org/EIPPerformanceMeasure/InfoSheet/9 accessed May 20, 2108).

Enhanced – Habitat is considered enhanced when actions are taken that heighten, intensify or improve one or more habitat functions for the benefit of special status species, water quality, property protection, recreation or scenic quality. Enhancements result in a net gain in function but not in area of the aquatic resource.

Restored – Habitat is considered restored when actions have been taken that re-establish or rehabilitate a SEZ with the goal of returning natural or historic functions and characteristics to a degraded SEZ. Restoration actions can rebuild a former SEZ and result in a gain in both SEZ area and function.

Appendix 3: Taken from "TRPA Code of Ordinances Regional Plan Update Committee Final Draft – October 24, 2012"

CHAPTER 53: INDIVIDUAL PARCEL EVALUATION SYSTEM

SEZ Identification

A stream environment zone (SEZ) shall be determined to be present if any one of the following key indicators is present or, in absence of a key indicator, where any three secondary indicators coincide; or, if Lo, Co, or Gr soils are present, where two secondary indicators coincide. Plant communities shall be identified in accordance with the definitions and procedures contained in the 1971 report entitled "Vegetation of the Lake Tahoe Region, A Guide for Planning."

A. Key Indicators

Key indicators are:

1. Evidence of surface water flow, including perennial, ephemeral, and intermittent streams, but not including rills or man-made channels;

2. Primary riparian vegetation;

3. Near surface groundwater;

4. Lakes or ponds;

5. Beach (Be) soil; or

6. One of the following alluvial soils:

a. Elmira loamy coarse sand, wet variant (Ev); or

b. Marsh (Mh).

B. Secondary Indicators

Secondary indicators are:

1. Designated flood plain;

2. Groundwater between 20 - 40 inches;

3. Secondary riparian vegetation; or

4. One of the following alluvial soils:

a. Loamy alluvial land (Lo);

b. Celio gravelly loamy coarse sand (Co); or

c. Gravelly alluvial land (Gr).

53.9 Procedure for Establishing SEZ Boundaries and Setbacks

53.9.2 SEZ Boundaries

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53.9.2. SEZ Boundaries

The boundaries of an SEZ shall be the outermost limits of the key indicators; the outermost limits where three secondary indicators coincide; or, if Lo, Co, or Gr soils are present, the outermost limits where two secondary indicators coincide, whichever limits establish the widest SEZ at any particular point. The outermost boundaries of a stream shall be the bank full width of such stream at the level of frequent high flow, which is defined as the level of flood with a recurrence interval of approximately 1.5 years.

Appendix4. Setbacks for SEZ's. Taken from the summary in Roby et al. (2015)

*Table 2. Setback widths applied to the Stream Environment Zone (*when present, lesser distance applies).*

SEZ Type	Flow Regime	Channel Type	Slope Condition	Setback Width (feet) from SEZ edge	Setback Width (feet) from Terrace*
Stream	Perennial	Confined	Good	25	15
			Average	35	20
			Poor	60	35
		Unconfined		50	
	Seasonally Flowing (ephemeral or intermittent stream)	Confined	Good	15	10
			Average	25	15
			Poor	40	25
		Unconfined		25	
Lake or Pond				10	
Other				10	

Topic Brief 2C Mapping Historic SEZ's, summary comments.

Comments on TRPA GIS teams approach to mapping current SEZ's and historical SEZ's

The approach that has been outlined by the TRPA GIS team seems to be best one based on available digitized maps. From my reading of the original Bailey land classification survey, it was based largely on the 1974 Soil Survey that didn't map with enough resolution to separately map higher gradient streams and it only lists capability classes which lump wet meadows, wetlands and floodplains. The degree of resolution in the 2007 NRCS Survey (USDA, NRCS, 2007) nearly quadrupled the degree of resolution. Still, the mapping units typically include several soil series in the map unit.

For purposes of rough analysis of SEZ's, we have been using the U.C. Davis Soil Web Soil Survey that simply overlays the soil survey map with either a satellite view or the U.S.G.S. topographic map to check along streamcourses. As an example, if we take Griff Creek beginning at the Lake Shore, the first map unit does outline the floodplain in unit # 9011, which includes six soils series. Most either are aquic suborders, or aquic great groups but they are not mapped separately, although the surveyor's clearly assign a percentage for each series to the map unit. Upstream in the higher elevations, the soil mapping unit for Griff creek no longer follows the lowest elevations of the ravine, and the map unit simply has descriptions such as: 1% Tahoe soils, (a hydric soil), or at higher gradients, aquic Xerorthents usually at only 1% of the map unit. As we get near the end of the permanent stream, the map subunits list 1% oxyaquic Xerorthents. This classification, added only in the 2007 survey is important because it is listed as a considerable area that was not included in the previous survey. And, these often contain very moist soils that may have aspen communities, with water tables within 30 cm of the surface during March to June. In high elevation cirques and low gradient floodplains, the designation of stream and wet meadow is more extensive, but still rarely 100% of one mapping unit. So, the soil survey maps are very reliable in telling you that an SEZ in *somewhere* in the mapping unit, but *not in demarcating it* in a map that can be digitized at resoltions of less than 2.5 acres (1 hectare).

Use of Bailey land capability plus Sinclair or Sinclair alone. Since Sinclair used the same 1974 soil survey as did Bailey, but added quadrupled resolution, and since it added SEZ area, perhaps it does not need to be considered with the overlay of the fours maps (Bailey, Sinclair, 2007 Soil Survey, SIG maps).

Smaller streams

From the overlay of the four methods being proposed by the TRPA GIS team, it looks like only the SIG map included streams that were not wide enough to warrant their own map unit in the Sinclair map and of 2007 Soil survey, so those would have to be added on the intersection (point occurring in all 4 maps) of the four maps. As you pointed out the mapped SEZ seems to continue from permanent streams into intermittent streams without distinguishing them. If at some point you wanted to distinguish intermittent steam courses, you could overlay the USGS topographic map and trace the intermittent reaches onto the SIG map.

Test of mapping system using individual parcel soil surveys

It is a very good idea to test the intersection of the 4 maps against the data for individual parcel soil surveys. With that amount of data, you should get a stringent test. Since most of the parcels are in urban and residential areas, it may be biased in favor of testing low elevation areas on large map units of hydric soils, but that may be where the greatest degree of uncertainty is, given the presence of soil inclusions in the mapping units based on the soil survey and capability zones.

We discussed having some statistical test of the ability of the map to predict the actual parcel evaluation. If we use a dichotomous "yes" or "no" to the question: "Does the parcel evaluation match the mapping unit?" Then you could make a 2x2 contingency table like the following hypothetical example:

Soil Evaluation of parcel	Mapped as SEZ	Mapped as not SEZ
Is SEZ	600 acres	50 acres
Is not SEZ	50 acres	1200 acres

First, the area not mapped as SEZ and not evaluated as SEZ can be eliminated from the table. Then the acreage converted to a percentage of 600 + 50 + 50. Then an "Expected percentage" could be generated:

"Expected" contingency table:

Soil Evaluation of parcel	Mapped as SEZ	Mapped as not SEZ
Is SEZ	100%	0%
Is not SEZ	0%	O% (because it is excluded)

Then the observed minus expected would be calculated for each cell, and a Chi Square Test calculated. That would give a "goodness of fit" probability for the hypothesis that the map and parcel evaluation correspond perfectly. The probability criteria should be set at a high level, since the map should be expected to do a good job of prediction.

Using acreage will bias the results to larger parcels. Another way is to use counts of individual parcels which may give more weight to a wider spatial distribution.

Manual method for checking changes from historic stream courses

As a way of manual way of searching for changes in the in streamcourse from the historic courses, I used the 2007 Soil Survey through UC Davis Soil Web tool to follow the major LTMP streams from the Lake going upstream. The Soil Web tool uses the 2007 Soil Survey Mapping units overlaid on a Google Earth interface. But, you can also toggle between satellite view and the USGS topographic map. So, for each stretch of stream you can see the Soil Survey map unit, the stream as designated on the USGS topo., and the satellite view. I used a screening method to look for places the current stream may differ from the historic SEZ:

(1) Where there is an hydric soil unit that is not along the stream as shown on the topo, then there may be a diversion from the historic course. With a satellite view I checked to see what it looks like,

(2) Where a stream on the topo that disappears and later reappears, then with a satellite view to check, (which is usually a culvert or longer diversion),

(3) Where the stream on the topo and in the satellite view seems too straight, or has some other artificially shaped course, or does not follow the bottom of a ravine,

(4) Where the stream on the topo ends upstream, and the map indicates oxyaquic Xerorthents, which may, on the satellite view, be seen as a wet meadow, or an aspen grove.

(5) Where there are obvious abandoned channels on the floodplain on the satellite view.

I think this is similar to your process in the sense that I had ended up looking for discrepancies between the topo, the satellite view and the soil survey map that might indicate diversions from, or filling of, the "historical SEZ". But, the soil map units were only useful for wetlands, large fens, stream floodplains, wet meadows more that about 2.5 acres (2015 Threshold Evaluation Report, Soil Conservation) or about 100 meters across (2.5 acres is about 1 hectare or 100 m x 100 m).

Use of old maps and GIS for detecting changes in stream courses since 1894

I have attached a paper by one of the groups in my class that were assigned the topic "Mapping of historic stream Environment Zones", which may or may not have anything useful. They did find a map from 1874. There is also another paper on "Soil classification changes in the SEZ within the Lake Tahoe Basin: implications for conservation and identification of SEZ's". The second paper was not send as a file so I'll have to mail it, but they digitized the 1974 soil map and overlaid it on the digitized 2007 soil survey and outlined areas of difference.

I found that the Keck Map collection at UNR has digitized the 1894 map that I had found in the Library. They have a 204 MB scan as a tif file that can be downloaded from this address:

https://contentdm.library.unr.edu/cdm/singleitem/collection/hmaps/id/4777/rec/9

The stream courses look like they were accurately surveyed. These might be useful to compare to the currently mapped stream course in the USGS topos or the SIG map to reveal changes in the historic stream courses since 1895 such as channelization, fill, diversion etc. For example, the 1894 scanned map could be georeferenced, and overlain with a recent USGS topos, or the SIG map or stream courses. Where that are significant differences in the 1894 vs. current stream courses, that could indicate diversions, channelization, fill, etc. I realized that the accuracy would be limited to plus or minus 10 meters but it is likely that significant changes would be indicated.

For the larger map units with hydric soils, greater than about 1 hectare, the 2007 soil survey should reveal historic SEZ's (except in cases of fill) since the gleying and other redoximorphic features probably persist for decades at least. But many map units contain "inclusions" of non-hydric soils that may exaggerate the extent.

USFS Map for meadows in the Northern Sierra

I was able to look at the maps of meadows on their UC Davis/USFS public interface. They definitely are mapping emergent marshes and peatlands as meadows, which I might put in another category of SEZ. In reading through the publication of Weixelman et al. (2011), they define meadows as anything with herbaceous vegetation. But, I see they do include the "wet meadows" near Stateline that I would recognize. I haven't been able to check any locations that I would call a "dry meadow". But, I am leading a Sierra Club field trip to the Washoe County State Park on June 3rd so I can do some "ground truth" investigation on wet vs. dry meadows, and what the minimum size of fen they map is. There are good examples of big and little fens, wet meadows and dry meadows in the State Park.

I have used the USFS map with the satellite imagery, toggling back and forth, and checked the Washoe Meadows State Park. There is a first approximation and a second approximation of the outlines for the various meadows that can be added. The first approximation does an excellent job of outlining fens that are about 0.5 to 1 hectare without significant lodgepole pine cover. The second approximation includes fringe portions of the fen with lodgepole pine of about 50% cover and seems to match my observations down to the scale of 10's of meters. As far as the inclusion of "dry meadows", the dry meadows in the Washoe Meadows State Park do not seem to be included. However, they may have been interpreted as grazed or disturbed.

Overall, I think the USFS Map or meadows is very thorough and accurate and will be a valuable overlay to include wet meadows. Places the overlap with the SIG and 2007 soil map may be large emergent marshes, larger peatlands.

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Topic Brief D

Tahoe Stream Environmental Zones and Climate Change: An overview on the potential impacts of climate change on SEZs and the functions and services they provide

Climate change predictions for California, the Sierra Nevada, and the Tahoe Basin

California will be one of the most climate-impacted areas of the United States in the coming century. The region is already experiencing dramatic changes to air temperature, precipitation patterns, snowpack and snowmelt dynamics, drought frequency, and the frequency and intensity of extreme weather events (CFCCA, 2018). Many of the most dramatic changes are taking place in the Sierra Nevada. In order to understand how these changes will affect stream environmental zones (SEZ), it's necessary to consider them in the context of historic patterns.

A mountain range in a Mediterranean region, the Sierra Nevada has comparatively cool and wet winters followed by warm and dry summers, with considerable variation along gradients in both elevation and longitude (Dettinger, 2016; Polade et al., 2017). Storms typically come off the Pacific Ocean between December and March, among the largest of which are atmospheric river events that deliver unusually large amount of water vapor to the region. The amount of precipitation that falls and whether it comes as rain or snow depends on orographic position, elevation, and local scale topographic relief. While snow tends to accumulate the most in the 2700 – 3100 m.a.s.l. range, western slope elevations in the 1500 – 1800 m.a.s.l. range tend to receive the most precipitation. A hallmark of precipitation patterns in the Sierra is high variability. Total annual precipitation can vary by <10% - 200% around the long term average (Dettinger, 2011) and large differences between years can result from just a few storms.

Despite the large degree of natural variation found in the Sierra, evidence for anthropogenic climate change has been observed since the 1950's (Barnett et al., 2008). Changes include increases in daytime and nighttime air temperatures, declines in annual average precipitation driven in large part by an increase in the frequency and severity of drought, an overall fractional decrease in the amount of precipitation falling as snow, and an increase in the frequency of extreme weather events. Such changes have impacted hydrological regimes, altering phenological patterns in the timing and magnitude of snowmelt. However, climate related changes are not occurring uniformly throughout the Sierra. The areas most affected by warming air temperatures and altered precipitation patterns are within the 1500 – 2500 m.a.s.l. elevation range. Regional climate predictions:

- Temperature: Although there is some uncertainty around temperature increases depending on how global emissions of carbon dioxide change, average air temperature in the Sierra is expected to increase by 3 – 6 °C over the next 80 years. The eastern and southern portion of the range are expected to warm more so than the central and northern Sierra. Generalized predictions of warming, however, don't take into account local scale topographic features that may mediate broader scale forcing (Daly et al., 2010; Lundquist et al., 2008, 2010). Weakening westerly winds and declining wind speeds may further differentiate eastern and western Sierra climate (Lundquist and Cayan, 2007). While specific climate models vary in their predictions of warming, there is broad agreement that by 2060 even the coolest years observed will be warmer than nearly all years in the past century.
- Precipitation: In contrast to strong long term warming air temperature trends, precipitation patterns are more variable. Variation among different climate models is large and the resulting change in precipitation patterns is spatially dependent. Consequently, long term trends in model averaged precipitation range from -5% to +10%, a range that is comparatively small with respect to the normal degree of interannual variation that is observed. Despite differences in long term trends among models, there is general agreement that variation among years will increase (Dettinger, 2016; Polade et al., 2017).

- Drought: Drought frequency is expected to increase as a result of reduced precipitation and increased evapotranspiration demand associated with warming air temperatures. Declines in precipitation are driven in part by a reduction in number of rain days, and an increase in the proportion of precipitation coming from a comparatively small number of large storms (Dettinger, 2016). The net effect is an increase in the probability of multi-year or multi-decadal drought (Ault et al., 2014; Cook et al., 2015).
- Extreme events: Along with the increased likelihood of drought comes an increase in the frequency of extreme weather events (Ault et al., 2014) and oscillations between very dry and very wet conditions (Safford et al., 2012; Swain, 2015). The hydrological impact of such events on receiving aquatic ecosystems can be large, resulting in decreased ecosystem productivity, altered chemistry, and degraded water quality (Sadro and Melack, 2012).
- Snowpack and declines in the proportion of precipitation as snow: Sierra-wide, the accumulation of winter snowpack is expected to decline by over 50% - 75% in the coming century (Barnett et al., 2008; Berg and Hall, 2017; Feng and Hu, 2007; Knowles et al., 2006). However, the changes in snowpack are expected to vary strongly with both latitude and elevation. Declines are expected to be largest at lower elevation sites, which are geographically more abundant in the northern Sierra. Higher elevation sites are expected to see less of a decline in snow because air temperatures are more likely to remain above freezing. Some models actually predict an increase in snow at higher elevations because of increased water vapor in the atmosphere. Despite such localized increases, overall snow covered area is expected to decline by 50% Sierra-wide. Positive feedbacks between warming trends and declines in snowpack may reduce snow cover even more (Walton et al., 2017).
- Snowmelt and streamflow: Widespread loss of snow and shifting precipitation patterns will have a dramatic impact on hydrology in the Sierra, causing concomitant increases in winter streamflows and decreases in spring and summer flows. As a result of decreasing winter snowpack, a decline in late spring snow, and a shift toward increased frequency of precipitation falling as rain, the onset of snowmelt is expected to begin by as much as 50 days earlier as less snow accumulates on the landscape (Lundquist et al., 2009; Sadro et al., 2018). Variation in the size of winter snowpack affects the timing and rate of snowmelt, which is critical for the Tahoe Basin. Large snowpacks contain more water, melt faster because they begin melting later in the season when solar inputs are larger, but take longer to melt overall than thinner snowpacks, which despite having less water, begin melting earlier in the season when solar inputs are lower (Harpold et al., 2012; Musselman et al., 2017). Thus under reduced snow accumulation scenarios, runoff patterns will shift toward an earlier date with discharge becoming flashier in response to the greater proportion of precipitation falling as rain, leaving less moisture within catchments later in the spring and summer when evapotranspiration demand is highest,. These changes in snowmelt hydrological dynamics will have important implications for water levels in SEZs, soil moisture, water stress for plants, and vegetative community structure.
- Wildfire: Climate factors such as increase drought frequency and severity, lower relative humidity, higher daytime air temperatures, lower nighttime relative humidity, and increased wind speeds have all contributed to increased wildfire frequency and severity (Abatzoglou and Williams, 2016). Indirect effects such as increased forest mortality and shifting seasonal vegetative phenologies may also play an important role.

The Tahoe Basin, which spans an elevation range from 1900 m.a.s.l. (lake level) to 3200 m.a.s.l. (Freel Peak) is particularly sensitivity to climate change effects because much of it lies within the 1500 – 2500 m.a.s.l. elevation range predicted to experience the greatest loss of snow (Barnett et al., 2008; Berg and Hall, 2017; Feng and Hu, 2007; Knowles et al., 2006). Empirical estimates of warming for the basin range from 0.06 to 0.47 ◦C decade $^{-1}$, which is higher than the Sierra-wide average (Coats, 2010) but lower than rates measured in the southern Sierra (Sadro et al., In revision). The percent of total precipitation falling in the Tahoe Basin as snow is declining by 1 -2 % decade $^{-1}$, as wet years become wetter and dry years become drier (Coats, 2010). Moreover, as the overall magnitude of variation in precipitation increases, the frequency and intensity of rain events is increasing. Hydrological impact of these changes were observed as a shift to earlier snowmelt in four of the five inlet streams to Lake Tahoe over a 25 year period ending in 2010 (Coats, 2010) . Although impacts to Lake Tahoe have been comparatively well studied, trends have not been evaluated in nearly a decade, and effects on SEZs throughout the basin are less well documented.

The role of climate as a stressor for SEZs and its effect on critical ecosystem functions

Climate is the most important factor governing the structure and function of stream environmental zones (Fig. 1). It sits atop our SEZ conceptual model because of its strength as a direct effect and its interactive effects through a wide range of other factors. As anthropogenic loading of greenhouse gasses into the atmosphere cause the climate system to shift outside historical ranges of variation, the role of climate as a driver shifts to that of a stressor (Table 3). Here, we outline the role of climate as a stressor for specific SEZ habitats and describe potential impacts on major ecosystem functions.

The specific climate related stressors for SEZ habitats are drought, increased runoff from rain, warming temperatures, increased evapotranspiration and reduction of soil moisture, increased frequency of extreme storm events and resulting hydrological flows, increased frequency and intensity of wildfire, increased sediment and nutrient load associated with fire and hydrological changes, increased incidence of non-native species invasions and altered food web structure, increased disturbance, and altered ecological interactions among organisms. The strength of climate as a stressor (i.e., sensitivity to climate change) may vary with physical watershed characteristics such as slope, aspect, soil lithography, and vegetation cover and type (Stewart, 2013). It’s important to note that rates of change of different climate attributes vary, and potential impacts may shift through time as interactive effects among different factors are altered (Costa-Cabral et al., 2013).

<u>Stream and riparian zones:</u>

The headwater streams and higher order rivers in the Tahoe Basin are a critical component of the hydrological system. They regulate hydrological and biogeochemical fluxes to downstream systems and because of their tight coupling to terrestrial and subsurface systems, are vital to nutrient and carbon cycling within catchments. By storing and cycling organic matter, they are responsible for the uptake, transformation and storage of inorganic nitrogen, reducing their downstream fluxes. They also contribute to sediment retention. They support food webs with complex structure utilizing both terrestrial and aquatic carbon sources, and export invertebrate biomass that serves as a food source in downstream communities. Along with wetlands, these areas are typically hotspots of biological and ecological diversity. The ecosystem services streams and riparian zones provide vary as a function size and watershed characteristics (Yeakley et al., 2016).

The climate sensitivity of stream and riparian areas is high. Streams quickly respond to changes in climate. Water temperatures will more readily reflect elevated daytime and nighttime air temperature minima. During drought, runoff will begin earlier in the streams (Coats, 2010) and temperatures are expected to increase 1.6 C for every 2 C rise in mean air temperature (Null et al., 2013; Stewart, 2013). The extent to which hydrological trends measured a decade ago have changed remains unclear. Regardless, streams with greater riparian vegetation cover and higher baseflows are less likely to warm (Arismendi et al., 2012). Coldwater habitat may be limited to the highest elevations in west-slope watersheds, and maintaining cold water habitat in other locations may require operating dams for thermal management as done in other parts of California (Null et al., 2013). Streamflow will respond rapidly to changes in hydrology. Earlier snowmelt and more precipitation as rain will alter the snowmelt dominated phenology for the flux of sediments and nutrients. Export to downstream ecosystems will increase as less uptake and cycling will occur at a time of year when light levels are lower (Riverson et al., 2013) and vegetation is dormant (Coats et al., 1976). Increased summer water temperatures and associated reduced dissolved oxygen concentrations will act as a physiological stress to organisms, reducing water quality. Connections between streams and riparian areas will be reduced under lower base flow conditions through much of the year, while geomorphological restructuring associated with extreme flows may occur suddenly. The resilience of streams to climate effects will depend in part on catchment characteristics such as slope and type of land cover, type and density of vegetation, and watershed size. More frequent scouring and disturbance may facilitate the spread of non-native plant species. Stream restoration activities will need to consider altered hydrographic timing, increased winter flows and reduced summer flows, flashier responses to extreme events or rain on snow events, and prolonged periods of drought.

<u>Wetlands and meadows:</u>

Wetlands and meadows provide valuable ecosystem services well beyond the comparatively small surface area they occupy. They provide vital hydrological and biochemical buffering during periods of high flows, reducing downstream sediment and nutrient loads, mitigating flooding, and facilitating groundwater recharge. They are critical habitats for invertebrates, amphibians, birds, and other wildlife. Moreover, they are recreational hotspots for hiking and fishing. Wetlands and meadows are largely dependent soil moisture and increasing persistence of drought will have lasting impact on ecosystem function and services.

Hydrology controls the structure and function of all aquatic ecosystems to varying degrees. Changes in hydrology can cause vegetation changes, shifts in community composition, and altered habitat structure. Such structural alterations, coupled with increased disturbance frequency, make SEZs more vulnerable to introductions of non-native species, conifer encroachment, and declines in meadow cover (Viers et al., 2013). The description of the model and Topic Briefs A and B described the critical timing of high water tables for transition of wet meadows to dry meadows, hydrologic conditions favoring conifer encroachment, and conifer encroachment on aspen stands. They also described the interaction of these factors on susceptibility to fire.

Wetlands are sensitive to climate change in that their ecosystem function is primarily determined by hydrology (Weixelman et al., 2011). Hydrological variation controls soil chemistry and plant community structure (Dawson et al., 2003). Changes in sedimentation rates, water velocity, and bed shear stress all affect the structure and composition of riparian plant communities and floodplain forests, which in turn regulate key ecosystem functions (Fetherston et al., 1995; Naiman et al., 1993; Viers et al., 2013). Encroachment by pine forests and a shift toward disturbance resistant species such as willow, cottonwood, or non-native species is expected as a result of ongoing climate change (DeFerrari and Naiman, 1994; Long et al., 2014; Millar et al., 2004). The implications of these changes for species diversity and ecological interactions are substantial but remain largely unresolved. Given the importance of wetlands and meadows as biological hotspots and the variability among them in sensitivity to climate, hydroclimate vulnerability assessments may be a useful tool for identifying candidate sites for conservation or restoration(Viers et al., 2013).

<u>Lakes and ponds:</u>

Lake Tahoe dominates the basin. It is both a unique ecological feature and a pillar of human interest in the region. In addition to Tahoe, there are numerous smaller lakes and ponds located throughout the basin. These impoundments are critical components of the hydrologic system and provide a broad range of ecosystem services (Schallenberg et al., 2013). Sitting at low points in catchments, Sierran lakes are vital areas of nutrient uptake, carbon cycling, and other biogeochemical reactions. Although oligotrophic, they are local hotspots of biodiversity and have food webs that support both aquatic and terrestrial communities. They play a critical role as part of the natural reservoir of snowmelt during the spring.

Climate is capable of affecting physical, chemical, and biological aspects of lakes. Variation in air temperature, relative humidity, and wind speed are all important factors regulating thermal structure, physical dynamics, and overall productivity of lakes ((Melack et al., 1997). The effects of climate are mediated to differing degrees by lake morphometry and catchment attributes (Kraemer et al., 2015; Sadro et al., In revision). The role of snowpack is particularly important for small lakes. By regulating the duration of ice cover and the volume of inflowing melt waters, variation in snowpack plays an important role in structuring the thermal dynamics of lakes and ponds (Sadro et al., In revision, 2018).

Considerable research has been done to explore and predict how Lake Tahoe will respond to ongoing climate changes (Coats, 2010; Coats et al., 2006; Costa-Cabral et al., 2013; Riverson et al., 2013; Sahoo and Schladow, 2008; Sahoo et al., 2013, 2016). While providing an exhaustive assessment is beyond the scope of this report, we focus on key lake attributes affecting productivity and water clarity. Because Tahoe doesn't freeze, long term trends in productivity reflect warming of surface waters and altered mixing dynamics (Goldman et al., 1989). Long term warming trends increase water column stability in Tahoe, lengthen the period of stratification, and reduce the frequency of deep mixing. A reduction in mixing and ventilating will increase the frequency of hypoxia or anoxia in the hypolimnion, possibly releasing phosphorus trapped in lake sediments (Beutel and Horne, 2018) and contributing to eutrophication and declines in water quality and clarity (Williamson et al., 2017). Climate change may also contribute to increased periphyton growth in near shore areas of Tahoe through two mechanisms. In years with little snowpack, inflowing meltwaters and the nutrient loads they carry are retained more in nearshore areas (Roberts et al., 2018), which may result in elevated nutrient concentrations. In addition, lower lake levels under drought conditions causes increased groundwater and nutrient flux into littoral habitats, further contributing to increased nutrient concentrations (Naranjo et al., 2017). The ecological and sociological implications of these changes would be considerable. Foreshadowing of the potential for rapid ecosystem level effects from increased climate variability was observed in 2017, when water clarity was lower than normal, possibly as a result of the combination of severe drought followed by a very wet year and resulting increased sediment loads to the lake.

Climate impacts to smaller lakes will be just as substantial, though the mechanisms may differ. Long term studies at Emerald Lake in the Southern Sierra and Castle Lake in the northern Sierra both suggest that ongoing changes in climate will increase lake productivity by increasing the length of the ice-free season and altering the timing of nutrient delivery and the onset of lake warming (Byron and Goldman, 1990; Sadro et al., 2018; Strub et al., 1985). The impact of changing climate on smaller lakes and ponds will vary substantially, and may be mediated by lake morphometry or local landscape characteristics (Sadro et al., In revision), creating a mosaic of lake responses in response to landscape-level heterogeneity.

Conclusion: Prioritizing climate related management goals for SEZs

Climate is arguably the most important external driver affecting SEZs. It directly regulates a broad range of ecosystem functions, especially those responding to variation in temperature and precipitation. From a management perspective there are few actions that can be taken at a local level to influence regional climate outcomes. However, there are ways in which climate impacts can be ameliorated. Many climate effects are modulated at the catchment level through interactions with other factors, such as the influence of land use on sediment loading and influence of riparian shading on stream temperatures. Moreover, because climate often interacts with other anthropogenic effects, its influence on a particular ecosystem function may be mediated through management actions targeting other stressors.

Although the conceptual model developed in this report provides a framework for identifying such interactions, we recommend a more detailed analysis be undertaken to: 1) identify emerging management risks; and 2) determine how current management activities and restoration actions can be modified to increase the resilience of SEZs in the facing of ongoing changes in climate. For example, although groundwater pumping is not currently a management priority, its effect on stream flows under changing hydrological regimes may differ substantially. Likewise, the direct and indirect effects of fire on SEZ habitats are likely to change in a way to impacts existing management and restoration targets. Restoration targets should be based on activities that buffer anthropogenic impacts to the watersheds and the Lake. For example, an integrated watershed approach to restoration designed to extend water residence time would for nutrient load reductions might involve upland forest fuel management, in-channel restoration, and targeted riparian zone revegetation. Managing for climate change impacts will require a holistic, system-wide approach focused on maintaining ecosystem function.

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