An Ecological Assessment of Perennial Wadeable Streams and Rivers in the Lahontan Region (2008-2018)

Prepared by Andrew C. Rehn

California Department of Fish and Wildlife

Aquatic Bioassessment Laboratory

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Overview

Stream bioassessment surveys have been conducted throughout the Lahontan Region by regional, state and federal agencies using both probabilistic and targeted survey designs. Data from probabilistic surveys of perennial, wadeable streams conducted from 2008-2018 were used to assess the overall ecological condition, or health, of regional streams using the California Stream Condition Index (CSCI) based on benthic macroinvertebrates and two independent indices of physical habitat condition, the Index of Physical Habitat (IPI) and the California Rapid Assessment Method (CRAM). Most sites were sampled in the Central Lahontan rather than the southern deserts or Modoc plateau due to lack of perennial stream length in the latter, so results from the Central Lahontan were emphasized. The CSCI indicated that 75% of the stream length in the Central Lahontan was in 'Likely Intact' (i.e., the healthiest) condition; IPI indicated slightly more than half to be in healthiest condition, CRAM indicated slightly less than half to be in healthiest condition. The CSCI and both physical habitat indices indicated that stream condition showed no consistent directional change in the Central Lahontan over the 11-year time frame assessed. Comparison of probabilistic and targeted sites to high-quality (relatively undisturbed) regional reference sites showed that 1) both probabilistic and targeted sites had significantly lower mean CSCI scores than reference sites; 2) targeted sites had significantly higher mean total nitrogen, ammonia, and alkalinity than probabilistic and reference sites, and 3) targeted sites had significantly higher mean riparian disturbance than reference sites. Despite the overall good ecological condition of regional streams based on estimates from probabilistic surveys, a summary of all sites (regardless of data source or survey design) where CSCI scores indicated either 'Likely Altered' or 'Very Likely Altered' biological condition was compiled to facilitate their potential prioritization in future monitoring efforts. In addition, cases where values for water chemistry analytes or physical habitat variables exceeded impairment thresholds used in recent statewide assessments were also summarized for sites where CSCI scores indicated biological impairment.

Introduction

Bioassessment is the science of using resident biological communities to infer the ecological condition of waterbodies such as freshwater streams and rivers. The Lahontan Regional Water Quality Control Board (Lahontan Board) has been a leader in developing bioassessment methods and tools for wadeable streams, mostly based on benthic macroinvertebrates (BMIs), since the approach first became used in California in the mid-1990s. Throughout the Lahontan Region (which encompasses the part of California draining to the Great Basin, including portions of the Modoc plateau, the east slope of the high Sierra, and the Mojave desert), BMI-based bioassessment has been used as a primary measure of water quality and habitat conditions, thus helping to allocate monitoring resources, assess the effects of permitted activities, prioritize remediation efforts and measure the success of remediation. The extensive and long-term bioassessment data sets collected by the Lahontan Board also have recently contributed to the development of two cornerstones of the SWAMP bioassessment program: 1) the California Stream Condition Index (CSCI, Mazor et al. 2016), the first stream index with statewide applicability, and 2) the Reference Condition Monitoring Program (RCMP, Ode et al. 2016), a statewide network of reference sites that define expected biological condition when human disturbance in the environment is absent or minimal.

Despite the Region's role in helping to establish bioassessment methodologies in California, no assessment that is specific to the Lahontan Region has been conducted to evaluate status and trends in wadeable stream condition over time. Statewide assessments of stream condition (e.g. Rehn 2015, 2021) have used ecoregion boundaries instead of Regional Board boundaries as reporting units; thus the central Lahontan was combined with the western Sierra as part of the larger Sierra Nevada ecoregion, and the northern-most and southern-most portions of the Lahontan were combined with the larger Desert-Modoc ecoregion. The purpose of this report is therefore to present an assessment of stream condition specific to the Lahontan Region which focuses on 5 questions:

1. What is the biological, chemical and physical condition of streams in the Region?
2. Is stream condition changing over time?
3. What is the relative condition of streams draining developed (agricultural or urban) vs. open landscapes?
4. How does stream condition at bioassessment sites targeted for sampling by the Lahontan Board compare to the regional average and to regional reference conditions?
5. What sites might be prioritized by the Lahontan Board for future sampling?

The regional average condition is estimated from probabilistic surveys where sites are selected randomly from a digitized stream network (sample frame). Each sampled site represents a portion of the total perennial stream length in the region (its statistical weight), allowing extrapolation of results from relatively few sampled sites to all wadeable stream length. Probabilistic surveys have been used to assess the ecological condition of wadeable streams and rivers throughout California since 2000. However, current sampling protocols have been in use since 2008, so this assessment is restricted to the years 2008-2018. Several probabilistic surveys encompassed all or part of the Lahontan Region during that time frame, most of which were recently aggregated for an updated assessment of statewide

stream condition (Rehn 2021). The exception was a survey conducted by the Tahoe Regional Planning Agency (TRPA) that was excluded from statewide aggregation, mostly because it used a higher-resolution sample frame than other surveys making statistical integration intractable, but also because it lacked benthic algae and most water chemistry data. However, because of the importance of the Tahoe Basin from a regional water quality management perspective, it was desirable to include data from that survey wherever possible in this assessment. The result is that the exact data sets used to answer each of the 5 questions above varied somewhat depending on the question (as explained below). Although not ideal, this approach seemed preferable to complete exclusion of a large data set of such regional relevance.

Data Sets

Data were aggregated from five different statewide and regional probabilistic surveys, two programs that target reference sites, and four programs that conduct bioassessment at targeted sites chosen for sampling based on several reasons including permit compliance, trend monitoring, filling data gaps, and evaluating suspected impairments (Table 1). Many of these programs revisit at least some sites over time (although revisit intervals vary among programs) so that 568 sampling events from 367 unique sites were included in the 2008-2018 Lahontan Region assessment (336 sites from the Central Lahontan and 31 sites from the Desert-Modoc, Figure 1).

Table 1. Statewide and regional bioassessment programs from which data were aggregated for inclusion in the 2008-2018 Lahontan Region assessment.

Program	Geographic Scope	Years Included	Number of Sites
Probabilistic Surveys			
National Rivers and Streams Assessment (NRSA)†	Statewide	2008-09; 2013-14; 2018	9
Perennial Streams Assessment (PSA)	Statewide except s. coast	2008-2018	90
USFS Management Indicator Species Program (MIS)	Sierra National Forests	2010-2018 (no 2011)	11
Tahoe Regional Planning Agency (TRPA)	Tahoe Basin	2009-2018	146
California Natural Resources Agency (CNRA)	NorCal private timber	2017	1
Reference Sites			
Reference Condition Monitoring Program (RCMP)	Statewide	2009-2018	51
Tahoe Regional Planning Agency (TRPA)	Tahoe Basin	2009-2018	7
Targeted Sites			
Heavenly Valley TMDL	Heavenly Valley	2010-2016	5
Lahontan Board	Lahontan Region	2008; 2017-2018	43
Squaw Creek (TRWQMP)	Squaw Creek Valley	2010-2016	3
USGS Xeric Flows Study	Big Rock Creek, LA Co.	2014	1
TOTAL			**367**

† The U.S. EPA's NRSA program is national in scope, but sites in California are distributed statewide.

Ecological Indices and Assessment Thresholds

Three ecological indices were used to assess stream condition in the Lahontan Region: the CSCI based on benthic macroinvertebrates (Mazor et al. 2016), the Index of Physical Integrity (IPI) based on reach-scale physical habitat data (Rehn et al. 2018), and the California Rapid Assessment Method (CRAM) which scores an assessment area based not only on physical and biological attributes, but also based on the amount of human disturbance influencing upstream hydrologic inputs and the buffer area around the site (CWMW 2013). Thresholds based on the 30th, 10th and 1st percentiles of index scores at statewide

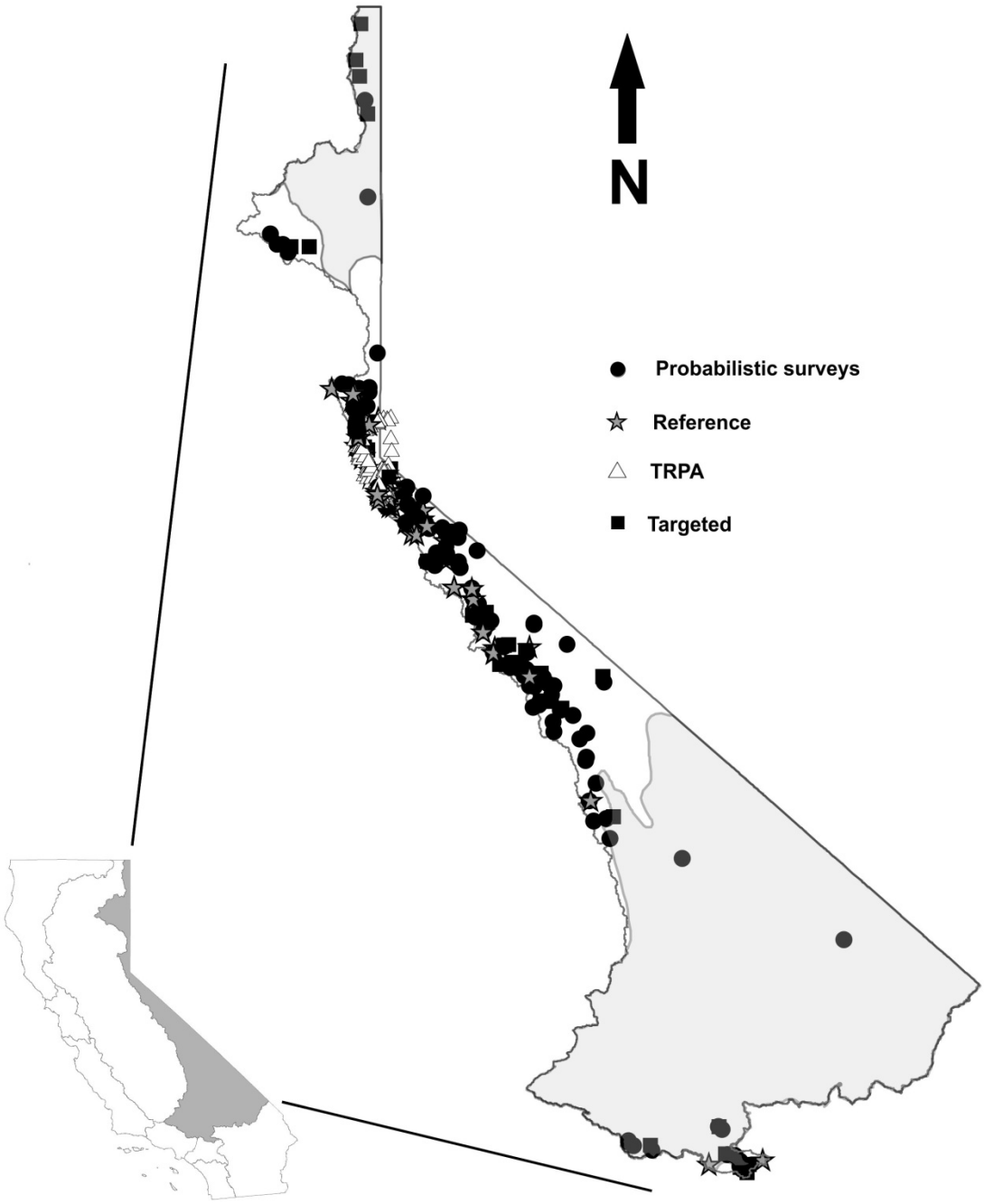

Figure 1. Map of 367 unique sites sampled by probabilistic surveys, reference site surveys and regional programs that targeted bioassessment sites in the Lahontan Region from 2008-2018. Shaded areas indicate where the Lahontan Region overlaps the Desert-Modoc ecoregion.

reference sites were used to define four stream condition categories for each of the indices (Table 2). Criteria for identifying reference sites in California were defined by Ode et al. (2016). Thresholds for CSCI were defined by Mazor et al. (2016), for IPI by Rehn et al. (2018), and for CRAM were recently defined for an updated assessment of statewide stream condition (Rehn 2021) based on reference site data aggregated by Rehn (2016) as part of a multi-indicator analysis of stream condition in California.

Table 2. Thresholds used to define stream condition categories for each index used in the 2008-2018 Lahontan Region stream condition assessment.

	Condition Category			
Index	**Likely Intact**	**Possibly Altered**	**Likely Altered**	**Very Likely Altered**
CSCI	≥ 0.92	0.91-0.80	0.79-0.63	≤0.62
IPI	≥ 0.94	0.93-0.84	0.83-0.71	≤0.70
CRAM	≥ 82	81-76	75-66	≤ 65

Inclusion/Exclusion of TRPA Data

As noted above, TRPA sites were not aggregated into the latest statewide assessment (Rehn 2021) and therefore lacked statistical weights calculated in the context of other survey designs that were included. An initial attempt to include TRPA sites in the Lahontan regional assessment by assigning equal weights to all probabilistic sites led to a spurious result for Question 2 (trends) whereby stream condition in the Central Lahontan subregion appeared to steadily decline over time from about 80% to only 50% of stream length estimated to be 'Likely Intact' according to CSCI scores. Such a dramatic decline in an 11-year period was inconsistent with results from other assessments that have mostly shown stable stream condition over time, both statewide (Ode et al. 2011; Rehn et al. 2015) and regionally (Mazor 2020; Rehn 2021), and did not seem explainable given current knowledge of the region, so TRPA sites were excluded from data sets used to answer Question 1 (status) and Question 2 (trends) and remaining sites retained their original weights from the statewide assessment. However, there were too few developed (i.e., ag or urban) sites in the remaining probabilistic data set to allow a land use component to the Lahontan assessment (with most urban sites coming from the TRPA Tahoe basin survey), so equal weights were used in the analyses to answer Question 3 (relative condition between developed and forested streams) so that TRPA data could be included. Finally, the analyses to answer Questions 4 and 5 did not rely on statistical weighting, so TRPA data were included.

Question 1: What is the biological and physical[1] condition of streams in the Lahontan Region?

Benthic Macroinvertebrates

For the Lahontan Region as a whole, nearly 50% of perennial, wadeable stream length was in 'Likely Intact' condition for the 11-year time period 2008-2018 according to the CSCI (Figure 2a). However, the percentage of stream length in the best biological condition during that time frame varied greatly by

[1] Interpretive indices are not developed for water chemistry data, so chemical conditions are compared between probabilistic sites, reference sites, and sites targeted for sampling by regional bioassessment programs under Question 4 below.

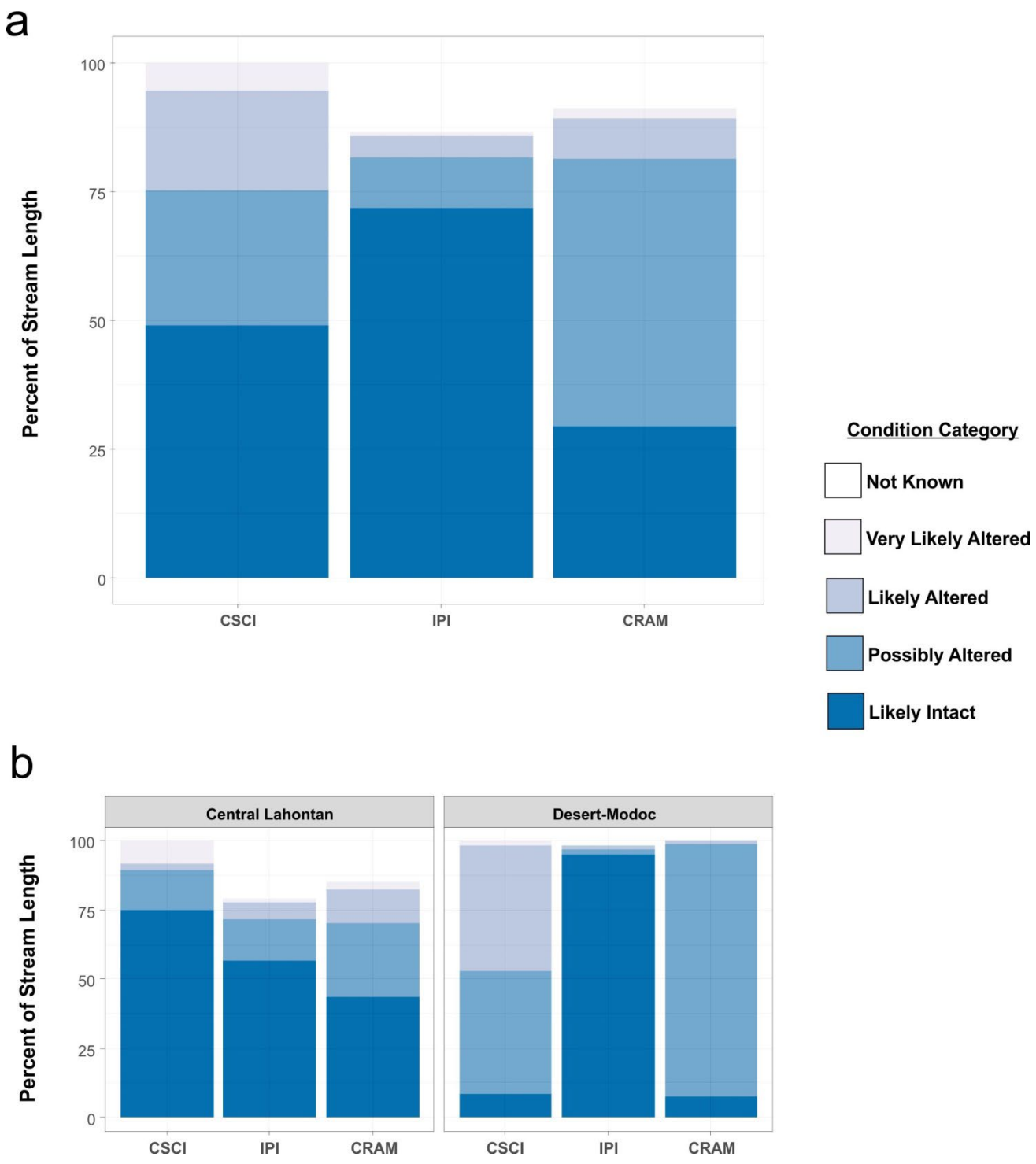

Figure 2. Bar charts of percent stream length in each of four stream condition categories (and percent Not Known where data were missing) for each of three bioassessment indices: a) region-wide, and b) by subregion.

subregion (Figure 2b), with the Central Lahontan having a much higher percentage of stream length in 'Likely Intact' condition (75%) than the Desert-Modoc (only about 10%). The small amount of 'Likely Intact' stream length in the Desert-Modoc was driven by 2 sites sampled in 2013 that had very high statistical weights (because they represented under-sampled strata), one of which scored as 'Possibly Altered' and the other as 'Likely Altered'. *Results from the Central Lahontan subregion (Figure 2b) are more likely reflective of the true overall regional status since that subregion had a much higher sample density more equitably distributed among strata than the Desert-Modoc subregion*.

Physical Habitat and CRAM

IPI and CRAM results are discussed together since both are physical habitat/ landscape condition indices and neither is a biological index. As with the CSCI, results for the region as a whole (Figure 2a) were more-or-less the average between the well-sampled Central Lahontan subregion and the under-sampled Desert-Modoc region (Figure 2b). In the latter, nearly all of the stream length was estimated to be 'Likely Intact' for IPI, and nearly all was estimated to be 'Possibly Altered' for CRAM, again because of 2 sites sampled in 2013 that had high statistical weights. *It is therefore reasonable to focus on results for the Central Lahontan subregion where 57% of stream length was 'Likely Intact' for IPI and somewhat less (44%) was 'Likely Intact' for CRAM*. CRAM also frequently assessed less stream length as being in 'Likely Intact' condition than other indices in the latest statewide assessment (Rehn 2021), most likely because presence of human disturbance (developed land, irrigated ag, etc.) reduces final index scores if within 2km upstream, within a 500-meter buffer perpendicular to the site, or even within 500 meters *downstream* of the site if within the riparian corridor. By contrast, IPI is based only on measures of in-stream habitat and riparian condition at the scale of the sampling reach, and like CSCI, therefore reflects response to human disturbance rather than presence of disturbance.

Question 2: Is stream condition changing over time?

To address this question, the full 11-year data set was divided into 8 overlapping 4-year time blocks, with each block shifting forward by one year. For example, the first time block included sites sampled in 2008-2011, the second included sites sampled in 2009-2012, and the last included sites sampled in 2015-2018. Each time block was labeled by its End-year in graphics that follow. Statistical weights (i.e., the amount of regional stream length represented by each site) were calculated separately for each 4-year time block. This approach is similar to a rolling average which is often used in trend analyses to smooth out short-term fluctuations and highlight longer-term trends or cycles.

Benthic Macroinvertebrates

Regional stream condition fluctuated during the 2008-2018 time period, but no apparent trend (i.e., no consistent directional change over time) was observed (Figure 3a). Over 80% of stream length in the Lahontan Region was estimated to be in 'Likely Intact' condition during the first 4 years of the study (2008- 2011). In End-years 2013 through 2016, 'Likely Intact' stream length decreased to below 40% of the total, then increased again starting in End-years 2017 and 2018. Again, the region-wide decline during End-years 2013-2016 was driven by the same two heavily-weighted Desert-Modoc sites sampled in 2013 (one that scored as 'Possibly Altered' and the other as 'Likely Altered', Figure 3b) that also

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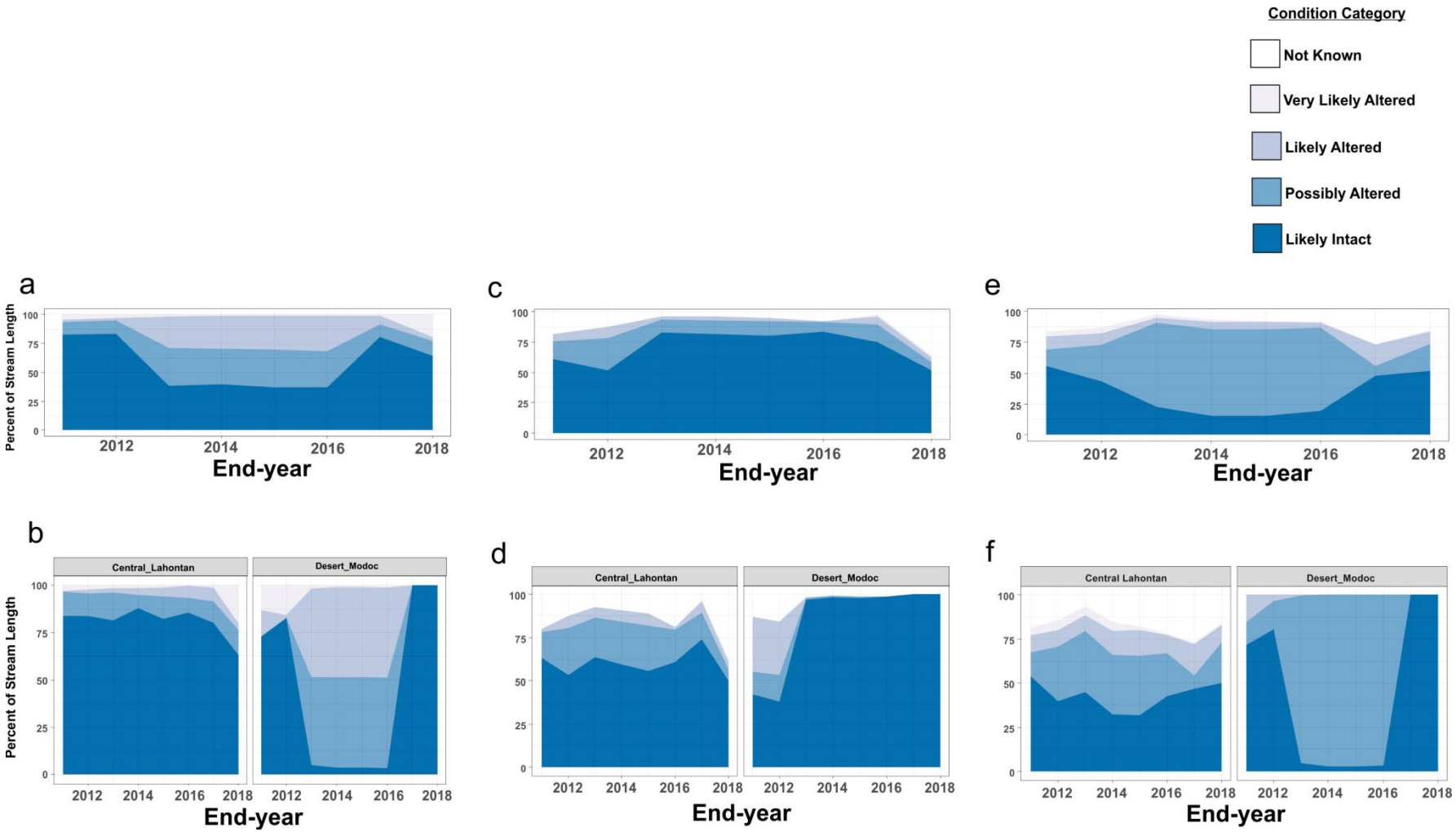

Figure 3. Stream condition over time based on CSCI scores (a,b), IPI scores (c,d) and CRAM scores (e,f). Top panels show condition over time for the Lahontan Region as a whole; bottom panels show condition over time per subregion.

skewed region-wide results for stream status (Question 1 above). The Central Lahontan subregion had over 80% of stream length in 'Likely Intact' condition for all End-years except 2018 when it dropped to 63% due to a single site sampled in 2018 that had an unusually high weight and scored as 'Very Likely Altered' for CSCI.

Physical Habitat and CRAM

Neither the IPI nor CRAM showed region-wide trends over time during the 2008-2018 assessment period (Figure 3c and 3e, respectively), with the percent of stream length in 'Likely Intact' condition being nearly the same at the beginning and end of the assessment period for both indices (and ignoring anomalies in End-years 2013-2016 caused by heavily-weighted Desert-Modoc sites as discussed above). At subregional scales, stream condition according to both IPI and CRAM fluctuated over time in the Central Lahontan but showed no consistent directional trends (Figure 3d and 3f, respectively), and was erratic and probably ignorable in the Desert-Modoc subregion.

Question 3: What is the relative condition of streams draining developed and open landscapes?

Sites were classified into two land use categories based on land use/land cover in the local[2] and entire upstream watershed: developed sites had ***either*** ≥ 10% urban land use ***or*** ≥ 25% agricultural land at local or watershed scales; open sites did not meet either of those criteria and had predominantly forested or scrubland land use in the upstream watershed, or a mixture thereof. Thresholds to classify sites as 'developed' were lower for the Lahontan Region than those used in statewide assessments (Rehn 2015, 2021) because very few Lahontan sites exceeded statewide thresholds where urban sites had ≥ 25% urban land use, and ag sites had ≥ 50% agricultural land use, at local or watershed scales. Also, there were only 2 Lahontan probabilistic sites that were classified as agricultural, even at the lowered 25% threshold, hence the lumping of ag/urban categories into a single 'developed' category.

As expected, less stream length draining developed watersheds was in 'Likely Intact' condition for CSCI and CRAM than for stream length draining open watersheds (Figure 4). By contrast, the percentage of stream length in 'Likely Intact' condition for IPI was nearly equal between developed and open watersheds (74% vs 72 %, respectively). It may be that IPI is less sensitive to the lowered regional thresholds used to classify sites as developed compared to statewide thresholds, i.e., the relatively low amount of urban and agricultural land use throughout the Lahontan Region compared to other regions in the state does not necessarily translate into in-channel or riparian disturbance that can be detected by the IPI at the scale of the sampling reach. That said, IPI may also be our least sensitive index even when higher levels of disturbance are present: in the latest statewide assessment, IPI assessed more stream length as 'Likely Intact' than other indices in 4 of the 6 PSA regions and statewide, although the differences in 'Likely Intact' stream length compared to the other indices were not always large (Rehn 2021).

[2] Land use was quantified at 3 spatial scales upstream of each sampling location: within 1km upstream, within 5km upstream, and in the full upstream watershed.

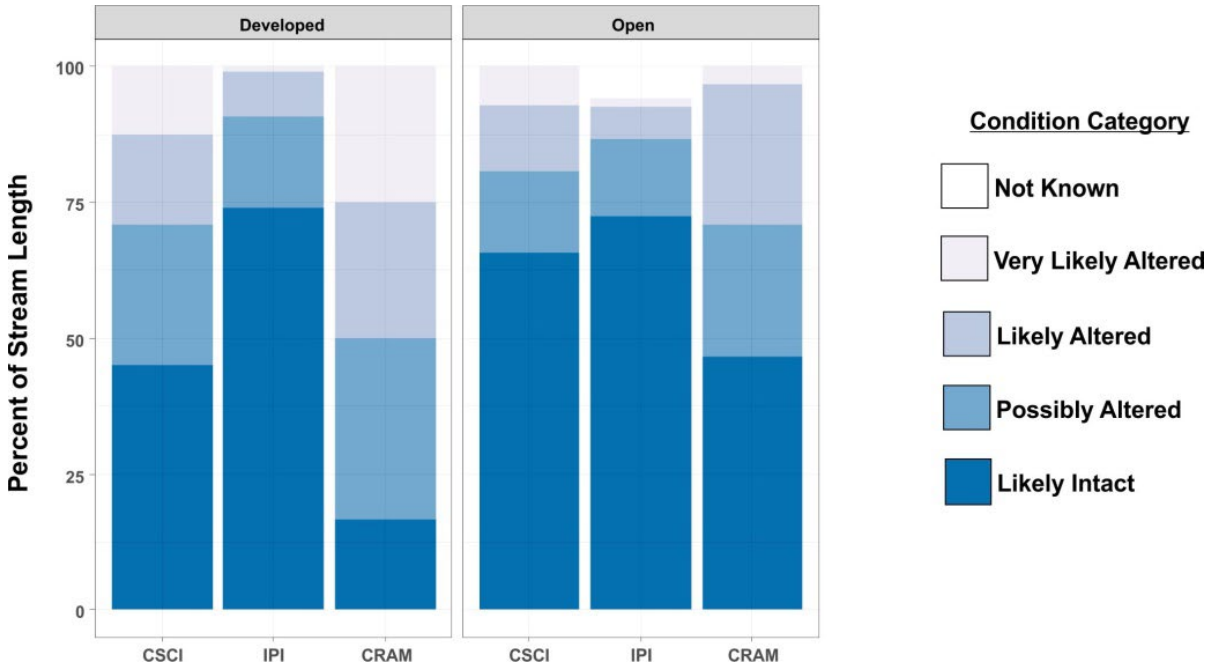

Figure 4. Bar charts of percent stream length in each of four stream condition categories (and percent Not Known where data were absent) for each of three bioassessment indices at survey sites classified by different types of land use (developed vs open).

Question 4: How does stream condition at bioassessment sites targeted for sampling by the Lahontan Board compare to the regional average and to regional reference conditions?

Bioassessment sites are often targeted for monitoring by regional water boards and other agencies because they have known impacts from environmental stressors on aquatic life use, water quality and/or physical habitat. These sites are often the target of management actions directed at improving environmental conditions including best management practices, implementation of TMDLs, or stream channel and riparian zone restoration. It can be useful to compare ecological conditions at targeted sites to the average regional condition estimated from probabilistic surveys and to regional reference conditions estimated from least-disturbed reference sites. The magnitude of ecological impacts at targeted sites can therefore be quantified relative to the region as a whole, allowing an assessment of the efficacy of management actions over time and a better understanding of whether desired recovery trajectories in response to management actions are being achieved.

An example of this approach is provided here for the Lahontan Region. Analysis of variance (ANOVA) was used to assess whether probabilistic sites, regional reference sites, and sites targeted for sampling by the Lahontan Board or other regional agencies had different mean values for CSCI, IPI, several water

chemistry analytes, and several physical habitat variables (Figures 5-7). Probabilistic sites were not weighted in ANOVAs, and all sites in the regional data set (Table 1) were included provided data were present. In a few cases, sites with high outlier values for water chemistry analytes were excluded from box plots if skewed y-axes made the bulk of the data distribution difficult to see (see Figure 6 legend below). ANOVA of CRAM scores was not provided because the TRPA survey and other regional programs did not collect CRAM data.

In most cases, the mean values of index scores, water chemistry analytes, and physical habitat variables were not significantly different between populations of probabilistic, reference, and targeted sites (Figures 5-7). Exceptions were CSCI, where probabilistic and targeted sites had significantly lower means than reference sites (Figure 5), total nitrogen, ammonia, and alkalinity, where targeted sites had significantly higher means than both probabilistic and reference sites (Figure 6), and riparian disturbance index where targeted sites had a significantly higher mean than reference sites (Figure 7)[3].

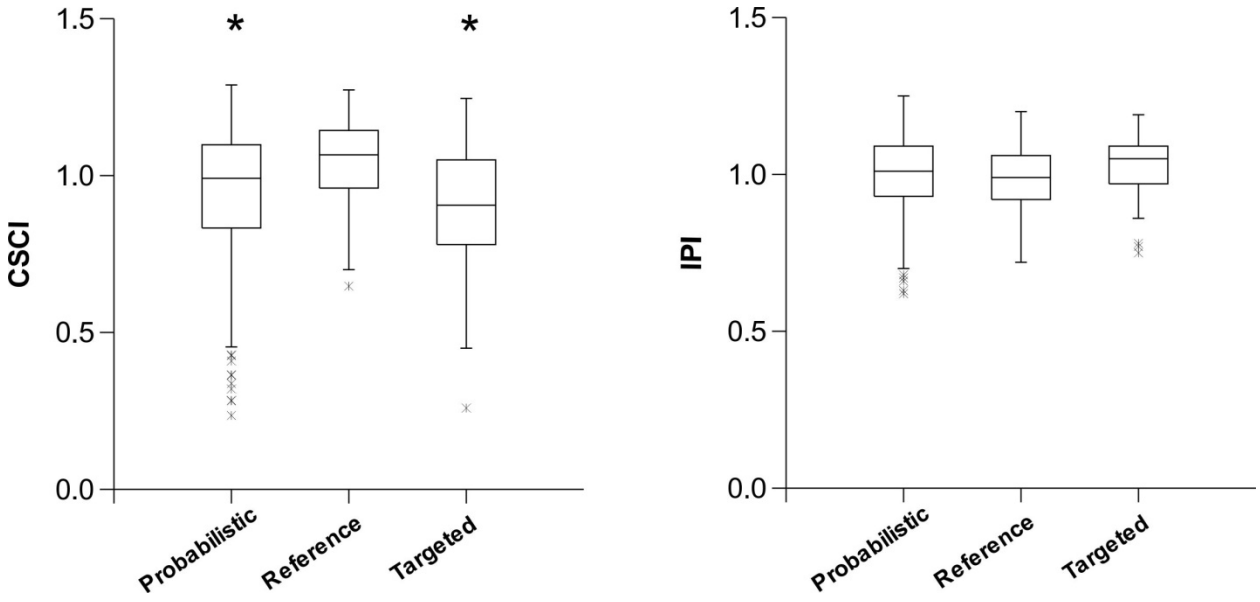

Figure 5. Box plots of CSCI and IPI scores at probabilistic sites, regional reference sites, and sites targeted for sampling by the Lahontan Board or other regional agencies. Asterisks indicate groups with significantly lower means than the reference distribution as estimated from ANOVA.

[3] *p*-values < 0.002 were considered significant as a Bonferroni correction for multiple (*n* = 20) simultaneous tests.

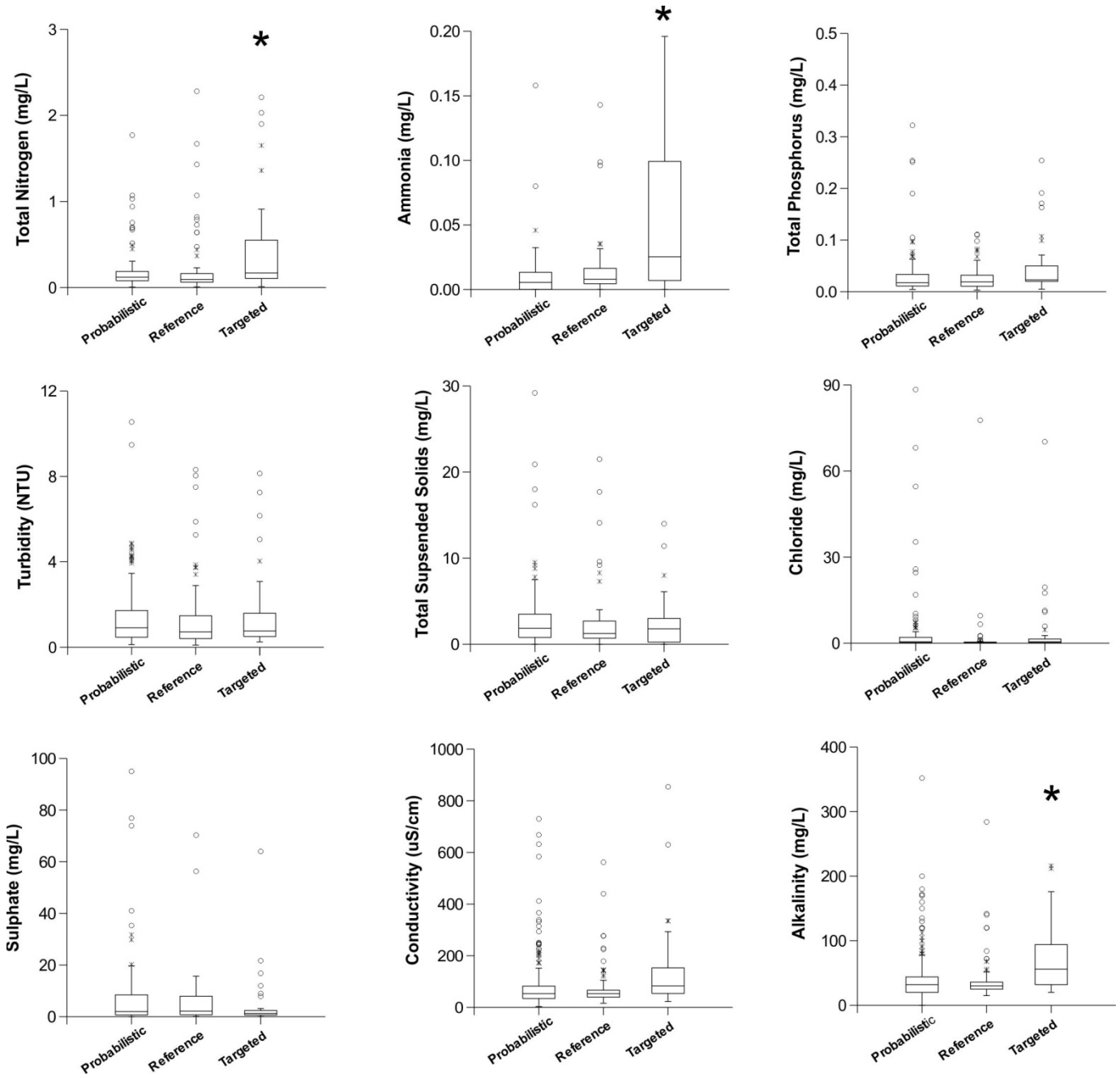

Figure 6. Box plots of the primary water chemistry analytes measured at probabilistic sites, regional reference sites, and sites targeted for sampling by the Lahontan Board or other regional agencies. Sites with extreme outlier values were omitted so that the main data distribution was apparent without having to log transform raw variables: 2 sites with total Phosphorus > 1 mg/L; 1 site with Turbidity > 30 NTU; 3 sites with Total Suspended Solids > 50 mg/L; 1 site with Chloride > 400 mg/L; 2 sites with Sulphate > 200 mg/L; 2 sites with conductivity > 1000 µS/cm; 1 site with Alkalinity > 700 mg/L. Asterisks indicate groups with significantly higher means than the probabilistic and reference distributions as estimated from ANOVA.

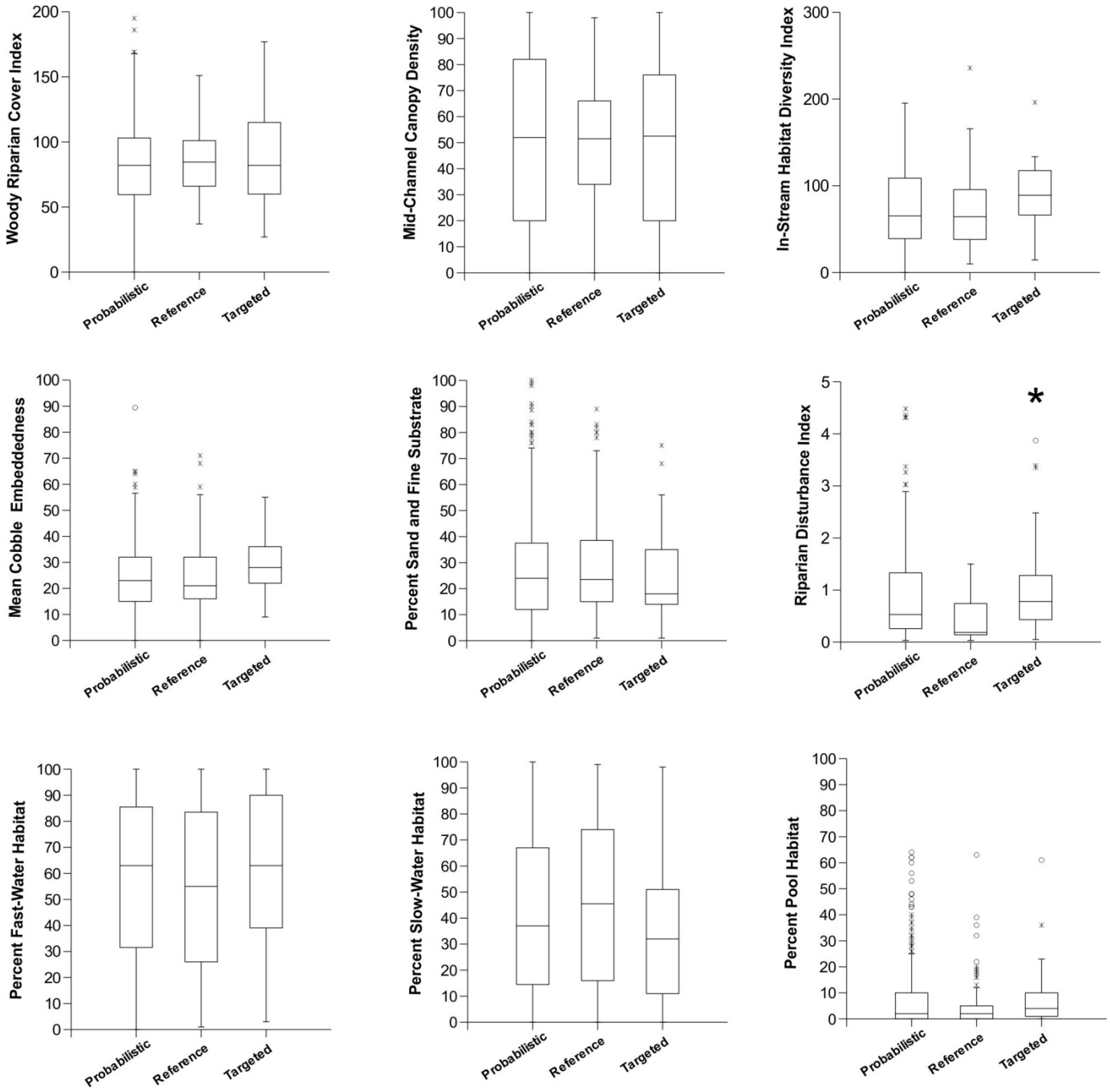

Figure 7. Box plots of the primary integrative physical habitat metrics at probabilistic sites, regional reference sites, and sites targeted for sampling by the Lahontan Board or other regional agencies. Asterisk indicates the group had a significantly higher mean than the reference distribution as estimated from ANOVA.

Question 5: What sites might be prioritized by the Lahontan Board for future sampling?

The CSCI is our most integrative measure of whether streams and rivers are supporting aquatic life uses. Probabilistic and targeted sites both had significantly lower mean CSCI scores than regional reference sites. Therefore, a summary of all 105 sampling events from 79 unique sites where CSCI scores were categorized as either 'Likely Altered' or 'Very Likely Altered' (regardless of data source, but mostly probabilistic sites) is provided here to facilitate their potential prioritization in future sampling efforts (Table 3; Figure 8). In addition, cases where values for chemical analytes or physical habitat variables exceeded impairment thresholds used in statewide assessments (Rehn 2015, 2021; Table 4) were also summarized for those sampling events/sites (Appendix 1). It is recommended that a tiered approach be used to prioritize these sites for follow-up sampling:

1. Sites sampled more than once and where CSCI scores were categorized as 'Likely Altered' or 'Very Likely Altered' at each visit should be prioritized for follow-up sampling and potential listing and/or causal assessment. There are 7 such sites listed in Appendix 1, each sampled between 2 and 5 times, 5 of them from the TRPA program. Sites in this group visited only twice to date should be sampled annually for another 2-3 years to establish whether biological impairment is a continuing pattern. TRPA sites sampled as many as 4 or 5 times already and found to be in 'Likely Altered' or 'Very Likely Altered' each time probably need only one more sampling event to confirm biological impairment. In all cases, complete water chemistry and physical habitat data should be collected at each sampling event to facilitate listing and/or causal assessment at sites where biological impairment is found to be a repeated pattern.

2. A single CSCI score does not represent high confidence that a site is biologically impaired. Sites with only 1 sample indicating 'Likely Altered' or 'Very Likely Altered' condition should be sampled annually over a period of at least 2-3 years to establish whether biological impairment is a continuing pattern. Additionally, sites lacking complete water chemistry and/or physical habitat data should be prioritized (e.g., most TRPA sites lack water chemistry), as filling in those data gaps will assist causal assessment at sites where biological impairment is found to be a repeated pattern. If additional prioritization within this group is desired, 'Very Likely Altered' sites could be prioritized over 'Likely Altered' sites, but all should be revisited eventually.

3. Sites with only 1 sample indicating 'Likely Altered' or 'Very Likely Altered' condition, but that have complete water chemistry and physical habitat data (e.g., most PSA sites), could be a third priority group. Again, these sites should be sampled annually over a period of at least 2-3 years to establish whether biological impairment is a continuing pattern, and are identified here as 'third tier' sites only because sites with missing data were identified as second priority. If additional prioritization within this group is desired, 'Very Likely Altered' sites could be prioritized over 'Likely Altered' sites, and/or sites with more exceedances (> 3) could be

prioritized over sites with fewer exceedances (≤ 3), but all should be revisited eventually. Complete water chemistry and physical habitat data should be collected at all sampling events.

4. Sites where CSCI score was categorized as 'Likely Altered' or 'Very Likely Altered' for some sampling events, but was categorized as 'Likely Intact' or 'Possibly Altered' for others, should be the last priority for follow-up sampling. Sites where a majority of samples were categorized as 'Likely Altered' or 'Very Likely Altered' could be a sub-priority within this group, whereas sites that were 'Likely Intact or 'Possibly Altered' for a majority of samples could be lower priority. Appendix 1 will have to be evaluated together with the full regional data set to identify these site groups (the full data set has been provided to regional staff).

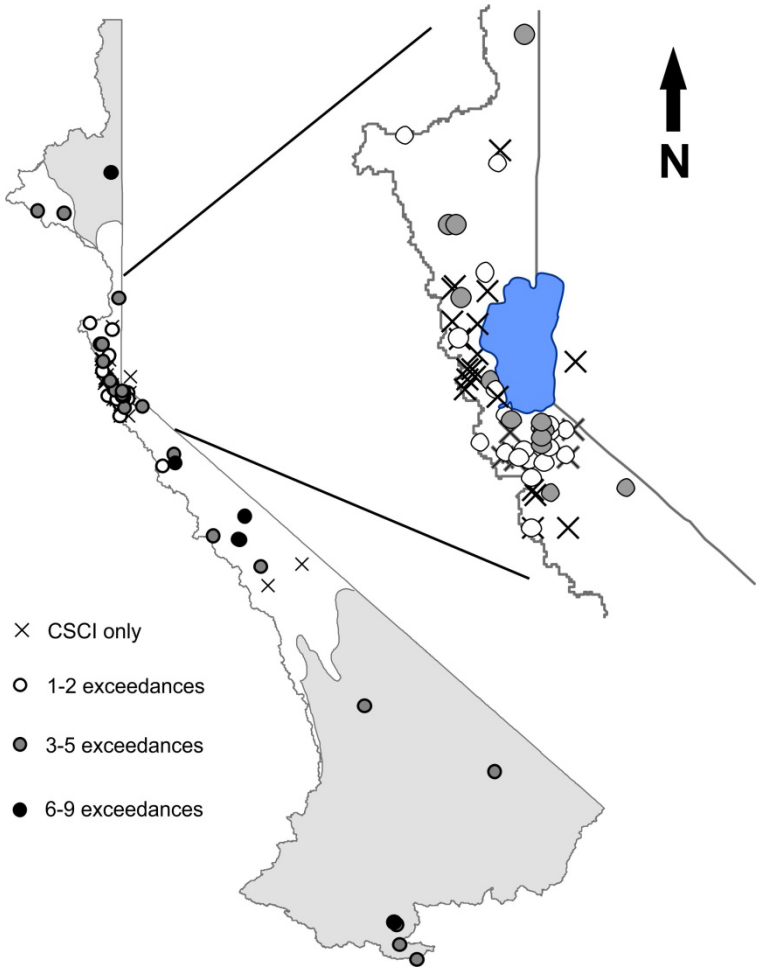

Figure 8. Map of 79 unique sites, most sampled by probabilistic surveys, where CSCI condition was 'Likely Altered' or 'Very Likely Altered' (CSCI score < 0.79). Number of exceedances refers to sites where thresholds in Table 4 were exceeded in addition to CSCI being <0.79. Shaded areas indicate where the Lahontan Region overlaps the Desert-Modoc ecoregion. Tahoe region inset added to better resolve high sampling density in that area.

Table 3. Summary of number of sampling events in different condition categories for CSCI, and number of sampling events where values for chemical analytes or physical habitat variables exceeded impairment thresholds used by Rehn (2015, 2021) in statewide assessments. See Table 4 for exceedance thresholds. Data gaps are also quantified. Physical habitat variables are from Kaufmann et al. (1999).

	CSCI	**IPI**	Chloride mg/L (CL)	Conductivity µS/cm (COND)	Total Nitrogen mg/L (NTL)	Percent sand & fine substrate (PCT_SAFN)	Total Phosphorus mg/L (PTL)	Total Suspended Solids mg/L (TSS)	Turbidity NTU (TURB)	Riparian disturbance index (W1_HALL)	Woody riparian cover index (XCMGW)	Mean percent embeddedness (XEMBED)	In-stream habitat diversity index (XFC_NAT)
Total Samples	568	502	234	527	234	517	238	200	249	530	517	465	515
Very Likely Altered/Likely Altered	105	37	24	26	48	149	42	28	40	77	101	25	24
Likely Intact/Possibly Altered	463	465	210	501	186	368	196	172	209	453	416	440	491
No data	0	66	334	41	334	51	330	368	319	38	51	103	53
Percent "good condition"	82%	93%	90%	95%	79%	71%	82%	86%	84%	85%	80%	95%	95%
Percent requires investigation	18%	7%	10%	5%	21%	29%	18%	14%	16%	15%	20%	5%	5%
Percent Missing Results	0%	12%	59%	7%	59%	9%	58%	65%	56%	7%	9%	18%	9%

Table 4 (modified from Rehn 2015, 2021). Criteria for identifying most-disturbed sites in 2 aggregate Level III ecoregions (see Stoddard et al. 2005 for aggregate ecoregion definitions) according to **CSCI**. The 90th percentile of stressor values at sites in 'Likely Intact' biological condition defined the most-disturbed threshold for variables where higher values indicate more disturbance (i.e., chloride, conductivity, total nitrogen, % sand and fines, total phosphorous, total suspended solids, turbidity, riparian disturbance index, mean embeddedness). The 10th percentile of stressor values at sites in 'Likely Intact' biological condition defined the most-disturbed threshold for variables where lower values indicate more disturbance (i.e., woody riparian cover index, stream habitat diversity index). Only thresholds relevant to the Lahontan Region are listed.

	Chloride mg/L (CL)	Conductivity µS/cm (COND)	Total Nitrogen mg/L (NTL)	Percent sand & fine substrate (PCT_SAFN)	Total Phosphorus mg/L (PTL)	Total Suspended Solids mg/L (TSS)	Turbidity NTU (TURB)	Riparian disturbance index (W1_HALL)	Woody riparian cover index (XCMGW)	Mean percent embeddedness (XEMBED)	In-stream habitat diversity index (XFC_NAT)
Sierra and North Coast	**10.1**	**282**	**0.27**	**35**	**0.056**	**5.5**	**2.4**	**1.27**	**55**	**46**	**18**
Xeric Southwest (= Desert-Modoc)	**3.2**	**205**	**0.173**	**47**	**0.048**	**9.2**	**4.2**	**1.9**	**45**	**57**	**19**

Conclusions

1. Wadeable streams in the Central Lahontan are, on average, in better biological condition than any other region in the state according to the CSCI. In a recent statewide assessment (Rehn 2021), the broader Sierra Nevada ecoregion and the North Coast had 65% and 70% of stream length in 'Likely Intact' condition, respectively, so the Central Lahontan with 75% in 'Likely Intact' condition is in slightly better condition than the broader PSA region in which it nests and the State's other best-scoring PSA region.
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2. The CSCI and both physical habitat indices (IPI and CRAM) indicated that stream condition showed no consistent directional change in the Central Lahontan over the 11-year time frame assessed.

3. Sites downstream of developed (agricultural/urban) land use had lower CSCI and CRAM scores than sites downstream of open (forested/shrubland) land use, but IPI scores were similar between developed and open sites.

4. Comparison of probabilistic and targeted sites to high-quality (relatively undisturbed) regional reference sites showed that 1) both probabilistic and targeted sites had significantly lower mean CSCI scores than reference sites; 2) targeted sites had significantly higher mean total nitrogen, ammonia, and alkalinity than probabilistic and reference sites, and 3) targeted sites had significantly higher mean riparian disturbance than reference sites.

5. Despite the Lahontan Region being in good ecological condition overall, many targeted and probabilistic sites were in degraded biological condition, the latter perhaps being previously unrecognized by the Lahontan Board as sites with potential issues.

6. Data aggregation and summarization made apparent that bioassessment programs in the Region do not always collect consistent data sets. Several lacked water chemistry, physical habitat measures, or both. Discerning whether biological impairment may be due to, or associated with, chemical analytes or physical parameters would greatly facilitate future regional assessments and site-specific causal assessments at sites listed for biological impairment.

Recommendations

1. Given that the broader Sierra Nevada ecoregion provides over a quarter of the surface water available for agriculture, recreation and municipal water supplies in California, protection of this important resource is paramount to sustaining both water quality and aquatic ecological integrity and should be a continued priority for the Lahontan Board.

2. Sites with CSCI scores that indicate 'Likely Altered' or 'Very Likely Altered' biological condition should be prioritized for follow-up sampling to confirm that biological degradation has occurred. A tiered approach was outlined above based predominantly on data density, first prioritizing sites where multiple samples over time have all indicated degraded biological condition, then prioritizing sites where only single samples over time have indicated degraded biological condition in order to establish more confidence in condition assessments at those sites, and finally prioritizing sites with multiple visits over time, but where biological condition fluctuates between impaired and not impaired. In the last group, sites with a majority of impaired samples (i.e., in 'Likely Altered' or 'Very Likely Altered' condition) could be a sub-priority, whereas sites with a majority of unimpaired samples (i.e., in 'Likely Intact' or 'Possibly Altered' condition) could be lower priority. The Lahontan Board could then use this report and results from follow-up monitoring to justify listing of such sites as biologically impaired, as appropriate.

3. Where possible, the Lahontan Board should leverage regional partner agencies to collect a standardized set of water chemistry analytes and physical habitat measures at all bioassessment sites, and also require the collection of these analytes and habitat measures with any permits that require collection of bioassessment data as part of pre- and post-project monitoring.

4. Low sample density in the Desert-Modoc was due to a preponderance of nonperennial stream length in the region. The Lahontan Board should invest more resources in sampling nonperennial streams in their region in order to help determine whether existing indices, calibrated for use in perennial streams, apply in nonperennial systems or whether new tools need to be developed. Similar efforts have been completed in southern coastal California, but have recently been expanded into northern California as part of the State Board's RCMP program. Collaboration between the Lahontan Board and RCMP could greatly improve tools available to assess not only the Desert-Modoc region, but also the Central Lahontan where approximately 40% of stream length has been estimated as nonperennial in previous statewide assessments.

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Appendix 1. List of 105 sampling events from 79 unique bioassessment sites where CSCI scores were categorized as either "Likely Altered' or 'Very Likely Altered' (i.e., scores were < 0.79). Cases where values for chemical analytes or physical habitat variables exceeded impairment thresholds used by Rehn (2015, 2021) in statewide assessments are highlighted and the number of exceedances tallied per site. See Table 4 for exceedance thresholds and definitions of variable acronyms.

StationCode	StationName	Date	CSCI	IPI	CL	COND	NTL	PCT_SAFN	PTL	TSS	TURB	W1_HALL	XCMGW	XEMBED	XFC_NAT	# exceedances
602PS0187	Adobe Creek above North Canyon Cr.	7/28/2016	0.70	0.63	0.85	89.70	0.75	100.00	0.25	6.70	9.48	0.15	6.00		1.80	8
603BSP111	Bishop Creek at National Forest Boundary	8/24/2017	0.72	1.11	0.22	32.50	0.18	19.00	0.02	1.70	0.41	0.50	83.00	11.00	100.30	--
603GSCADC	Glass Creek ~4.1mi above Deadman Cr.	8/25/2010	0.71	0.86	0.19	56.70	0.05	39.00	0.08	21.50	0.56	0.00	63.00	50.00	20.40	4
603PS0079	Owens River ~1mi above Benton Crossing Rd.	8/1/2012	0.72	0.98	25.80	366.40	0.31	51.00	0.19	5.00	2.47	1.36	0.00		0.50	9
603PS0132	Owens River ~4mi above Rock Cr.	7/17/2013	0.76	1.05	24.60	127.50	0.52	63.00	0.11	4.00	1.07	0.31	97.00	30.00	14.60	5
603UOW003	Upper Owens River, Ebasco 417S	8/25/2008	0.79			335.00						2.20				2
603UOW003	Upper Owens River, Ebasco 417S	8/25/2008	0.75			335.00						2.20				2
605FC0324	Crooked Creek, NF ~0.9mi above confluence	7/10/2018	0.60		1.15	245.30	0.08		0.04	2.10	0.88					--
609PS0053	Amargosa River	5/14/2008	0.64	0.86	439.00	4234.00	0.49	36.00	0.03		0.92	0.00	48.00	65.00	8.20	5
620PS0669	Darwin Creek above Darwin Falls	8/17/2010	0.53		35.30	584.00	0.24	49.00	0.04	7.80	1.00	0.07	36.00	20.00	64.10	5
628DEP001	Deep Creek above Deep Cr Lake	6/28/2017	0.78	0.92	17.50	125.00	0.21	53.00	0.02	-0.80	0.30	3.39	53.00	28.00	196.10	4
628MOJ001	Mojave River, at Upper Narrows	6/26/2017	0.52	0.77	70.20	629.80	0.89	75.00	0.05	1.30	1.09	3.35	41.00	51.00	133.00	7
628MOJ002	Mojave River, below Forks Res	6/26/2017	0.68	1.02	19.50	293.20	0.20	42.00	0.07	1.90	4.03	1.28	27.00	20.00	72.00	5
628PS0715	Mojave River below Hwy 18	6/9/2010	0.67	0.73	68.10	668.00	1.07	74.00	0.04	4.90	1.61	2.05	88.00		0.00	7
628PS1483	Mojave River ~2.1mi above Hwy 18	5/22/2013	0.59	1.12	54.60	632.00	1.77	55.00	0.03	0.50	0.63	0.33	167.00		25.50	4
631PS0151	West Walker River below Grouse Cr.	7/13/2015	0.79	0.91	2.04	100.30	0.10	38.00	0.02	2.90	4.32	1.14	52.00	49.00	30.50	4
631PS0209	Leavitt Creek ~1.5mi below Sardine Cr.	9/6/2017	0.76	1.13	0.12	49.00	0.13	12.00	0.02	18.00	0.43	0.14	122.00	24.00	86.80	1
631PS0215	Hot Creek ~0.9mi above Little Walker River	9/12/2017	0.51	0.94	88.40	1475.00	0.26	55.00	0.25	6.80	4.62	0.78	35.00	32.00	50.50	7
633PS0142	Carson River, WF above Diamond Valley Rd.	6/30/2014	0.47	1.04	1.07	84.00	0.19	40.00	0.03	20.90	4.87	1.71	87.00	38.00	65.20	4
633WE0991	Carson River WF ~ 1.6 miles up Blue Lakes Rd.	9/9/2014	0.74	1.04	0.12	77.80	0.14	16.00	0.01	1.60	1.95	0.10	77.00	8.00	35.80	--
634BLW002	Blackwood Creek above Barker Pass Bridge	9/26/2017	0.77	1.05	0.14	84.60	0.11	23.00	0.04	1.90	0.61	0.50	42.00	36.00	60.30	1
634GACALL	Glen Alpine Creek ~1mi above Lilly Lake	9/10/2013	0.76	1.00	0.16	32.40	0.06	19.00	0.01	0.50	0.10	0.14	99.00	20.00	36.40	--
634HVC-1	Heavenly Valley Creek at Sky Meadows	8/10/2010	0.67													--
634HVC-1	Heavenly Valley Creek at Sky Meadows	8/29/2011	0.61													--
634HVC-1	Heavenly Valley Creek at Sky Meadows	7/28/2014	0.26													--
634HVC-2	Heavenly Valley Creek below Patsy's	8/29/2011	0.75		0.45		0.12		0.02		1.00					--
634HVC-2	Heavenly Valley Creek below Patsy's	7/28/2014	0.75		1.00		0.16		0.02		1.30					--
634HVC-2	Heavenly Valley Creek below Patsy's	6/11/2015	0.77		0.95		0.18		0.02		3.08					1
634REFGNL	General Creek Reference	8/1/2013	0.70	1.04		32.10		19.00				0.00	151.00	27.00	103.40	--
634REFSAX	Saxon Creek Reference	8/20/2012	0.72	0.77		53.20		89.00				0.00	70.00		95.40	2
634S10114	Upper Truckee River	8/24/2010	0.63	0.88		80.00		70.00				2.28	32.00	20.00	25.40	3
634S10114	Upper Truckee River	9/25/2018	0.73	0.85		110.00		50.00				0.00	18.00		28.90	2
634S11015	Ward Creek	8/30/2011	0.72	1.12		35.00		11.00				0.00	95.00	35.00	88.20	--
634S11162	Upper Truckee River	9/15/2011	0.73	1.02		75.90		57.00				0.85	91.00		19.10	1
634S12195	Susie Lake Creek	8/30/2012	0.79	0.79		32.00		2.00				0.00	7.00	4.00	31.40	2
634S12198	Tallac Creek	8/16/2012	0.28	0.62		78.00		98.00				0.14	16.00		82.10	3
634S12201	Angora Creek	7/18/2012	0.53	0.97		13.50		31.00				0.14	69.00	22.00	69.70	--
634S13231	General Creek	8/15/2013	0.78	1.09		35.20		3.00				0.00	119.00	23.00	102.00	--
634S13242	Upper Truckee River	9/16/2013	0.69	0.88		124.10		24.00				2.75	9.00	2.00	16.30	3
634S13242	Upper Truckee River	8/30/2017	0.74	0.88		64.80		42.00				1.43	16.00	13.00	11.80	4
634S14235	Ward Creek	8/7/2014	0.58	0.97		70.60		10.00				1.14	57.00	34.00	33.90	--

Appendix 1 (continued).

StationCode	StationName	Date	CSCI	IPI	CL	COND	NTL	PCT_SAFN	PTL	TSS	TURB	W1_HALL	XCMGW	XEMBED	XFC_NAT	# exceedances
634S14243	Blackwood Creek	8/13/2014	0.36	1.03		44.80		28.00				0.15	65.00	7.00	39.60	--
634S14245	Glen Alpine Creek	8/5/2014	0.76	0.87		37.90		0.00				0.97	62.00	11.00	57.50	--
634S14247	McKinney Creek	8/20/2014	0.70	1.05		52.80		11.00				0.33	139.00	22.00	104.50	--
634S15274	Upper Truckee River	9/18/2015	0.43	1.12		136.70		56.00				0.00	89.00		78.20	1
634S15286	Rubicon Creek	6/18/2015	0.65	1.08		208.10		73.00				0.32	93.00		122.80	1
634S15290	Trout Creek	8/26/2015	0.72	1.00		61.10		60.00				0.00	46.00		37.80	2
634S15298	Upper Truckee River	8/19/2015	0.54	1.03		124.30		56.00				1.54	70.00	0.00	55.20	2
634S16265	Angora Creek	6/21/2016	0.48	0.82		11.70		46.00				0.00	59.00	9.00	58.60	2
634S16291	Burton Creek	6/14/2016	0.46	1.06		63.30		21.00				0.30	86.00	15.00	155.00	--
634S16311	Watson Creek	6/16/2016	0.34	0.92		36.10		37.00				0.00	60.00	25.00	94.50	1
634S16313	Hidden Valley Creek	7/6/2016	0.63	0.85		8.80		27.00				0.00	50.00	11.00	37.60	1
634S16317	Big Meadow Creek	8/8/2016	0.74	1.08		49.70		12.00				0.37	95.00	22.00	160.50	--
634S17325	Upper Truckee River	8/14/2017	0.63	1.14		28.90		15.00				0.00	75.00	18.00	56.40	--
634S17334	Grass Lake Creek tributary	6/29/2017	0.65	0.72		15.00		64.00				1.27	108.00		58.00	3
634S17342	Tallac Creek tributary	6/26/2017	0.74	1.01		14.50		32.00				0.00	96.00	8.00	86.60	--
634S17400	Logan House Creek	7/25/2017	0.70	1.01		115.70		27.00				0.31	85.00	14.00	53.10	--
634S18374	General Creek	6/19/2018	0.65	1.14		10.00		23.00				0.00	115.00	14.00	52.80	--
634TPA025	Glen Alpine	8/8/2013	0.67	0.96		39.80		37.00				0.00	95.00	11.00	26.00	1
634TPA041	Upper Truckee River	8/12/2009	0.79	1.13		95.00		32.00				1.16	61.00	19.00	29.10	--
634TPA041	Upper Truckee River	9/17/2015	0.69	1.15		69.40		37.00				0.22	102.00	16.00	69.50	1
634TPA050	Trout Creek	8/27/2009	0.41	0.68		49.00		99.00			1.25	0.24	8.00		5.50	4
634TPA050	Trout Creek	9/14/2011	0.68	0.82		42.10		76.00				0.00	7.00		10.00	4
634TPA050	Trout Creek	8/20/2013	0.43	0.86		56.00		65.00				0.00	18.00		13.60	3
634TPA050	Trout Creek	9/8/2015	0.58	0.67		62.60		90.00				0.00	22.00		39.60	3
634TPA050	Trout Creek	9/19/2018	0.56	0.96		60.00		78.00				0.00	105.00		15.00	2
634TPA061	Trout Creek	8/3/2009	0.79	0.87		48.00		55.00			1.23	0.48	49.00	33.00	32.80	2
634TPA070	Cascade Creek	9/3/2009	0.71	0.90		16.00		4.00			0.66	2.10	55.00	38.00	87.00	2
634TPA070	Cascade Creek	8/25/2011	0.61	0.93		9.40		3.00				0.48	71.00	18.00	114.40	--
634TPA070	Cascade Creek	8/5/2013	0.64	0.92		13.00		1.00				0.66	90.00	15.00	95.30	--
634TPA070	Cascade Creek	6/9/2015	0.72	0.93		13.00		12.00				0.99	82.00	31.00	81.50	--
634TPA075	Lonely Gulch	8/31/2009	0.67	0.93		27.00		32.00			0.41	4.32	48.00	36.00	50.30	2
634TPA075	Lonely Gulch	7/11/2011	0.70	0.73		17.80		18.00				2.39	37.00	26.00	83.00	3
634TPA075	Lonely Gulch	7/9/2013	0.61	1.13		32.30		15.00				2.70	69.00	32.00	58.40	1
634TPA075	Lonely Gulch	6/10/2015	0.45	1.05		332.00		35.00				1.56	99.00	28.00	77.70	3
634TPA085	Truckee River	9/19/2013	0.49	0.93		101.70		80.00				0.26	90.00	9.00	35.80	1
634TPB103	McKinney Creek	6/29/2010	0.59	1.02		22.00		15.00				0.35	73.00	30.00	148.20	--
634TPB103	McKinney Creek	7/12/2017	0.59	0.99		14.20		1.00				0.33	71.00	20.00	115.90	--
634TPB134	Rubicon Creek	6/6/2016	0.24	0.92		19.30		33.00				0.14	58.00	18.00	160.00	--
634TPB141	Upper Truckee River	9/19/2012	0.74	1.05		129.90		43.00				0.14	43.00	3.00	23.50	2
634TPB141	Upper Truckee River	6/12/2014	0.67	1.13		36.10		39.00				0.00	53.00	10.00	10.90	3
634TPB151	Quail Creek	6/28/2010	0.67	0.99		54.00		20.00				0.69	116.00	30.00	128.10	--
634TPB151	Quail Creek	7/5/2017	0.63	1.01		24.80		20.00				0.80	119.00	24.00	114.70	--
634TPB153	Angora Creek	7/18/2012	0.78	1.05		58.60		34.00				0.00	27.00	30.00	40.90	1
634TRT002	Trout Cr 4th Ord Lower	8/25/2016	0.62	0.93		39.40		62.00				0.00	46.00		37.60	2

Appendix 1 (continued).

StationCode	StationName	Date	CSCI	IPI	CL	COND	NTL	PCT_SAFN	PTL	TSS	TURB	W1_HALL	XCMGW	XEMBED	XFC_NAT	# exceedances
634TRU231	Truckee River, Upper ~0.6mi below Grass Lk. Cr.	7/29/2014	0.79	1.11	2.93	72.40	0.11	25.00	0.02	1.10	0.67	0.59	65.00	0.00	35.50	--
634UHC-1	Hidden Valley Creek, Upper	6/8/2015	0.58													--
634UHC-1	Hidden Valley Creek, Upper	7/22/2016	0.73													--
634UTRADC	Truckee River, Upper ~0.8mi above Dixon Cyn. Cr.	8/21/2013	0.65	1.06	0.19	86.10	0.15	24.00	0.06	2.70	5.88	0.00	106.00	10.00	27.40	2
635PS0018	Truckee River ~1mi below Bear Creek	7/20/2009	0.36	0.94	1.83	55.60	0.05	74.00	0.01	1.20		1.06	40.00	20.00	15.50	3
635PS0146	Donner Creek ~1.2mi above Hwy 89	9/3/2014	0.28	0.94	16.90	112.60	0.09	49.00	0.01	1.40	0.66	1.88	56.00	9.00	31.90	3
635PS0210	Donner Creek ~0.2mi above Hwy 89	9/5/2017	0.68	0.85	10.30	85.20	0.23	22.00	0.03	3.00	0.87	3.37	51.00	37.00	19.00	3
636PS0070	Little Truckee River ~1mi above Cold Stream	9/21/2011	0.71	1.11	0.19	73.00	0.09	14.00	0.03	2.30	1.79	1.50	66.00	17.00	23.70	1
636PS0086	Little Truckee River ~0.8mi below Stampede Res.	9/26/2012	0.65	0.91	0.48	67.20	0.17	11.00	0.01	2.80	2.14	0.16	59.00	5.00	23.20	--
636PS0150	Little Truckee River ~2.4mi below Worn Mill Cyn.	7/29/2015	0.78	0.97	0.62	730.00	0.14	22.00	0.01	2.60	2.10	0.00	61.00	8.00	6.00	2
637PS0214	Long Valley Creek ~2.5mi above Evans Cyn Cr.	8/21/2018	0.32	0.66	2.40	248.00	0.94	91.00	0.07	1.30	1.25	1.05	73.00	33.00	5.10	5
637SSN077	Susan River	7/16/2010	0.47	0.88		41.00		62.00				1.10	77.00	35.00	49.80	1
637SSN077	Susan River	6/27/2012	0.47	0.71		50.00		62.00				1.10	77.00	35.00	49.80	2
637SSN077	Susan River	8/2/2016	0.66	0.82	0.17	65.00	0.45	63.00	0.03	1.20	1.68	0.00	89.00	64.00	39.80	4
637SUS004	Susan River at Commercial Road	9/11/2018	0.45	1.05	4.69	242.00	0.01	68.00	0.06		5.05	0.92	141.00	25.00	14.50	4
639PS1279	Smoke Creek ~4mi above Sage Hen Spring	6/11/2013	0.68	1.01	1.62	126.80	0.69	27.00	0.05	9.50	4.69	0.32	22.00	20.00	15.50	6
BIO-SC1	Squaw Creek	7/25/2012	0.78			153.00										--
BIO-SC1	Squaw Creek	7/20/2016	0.78			69.00										--
BIO-SC2	Squaw Creek	7/29/2010	0.67			52.00										--
BIO-SC2	Squaw Creek	7/19/2016	0.75			69.00										--