Background

The analysis of the Dry Creek watershed was performed using a method developed by the US EPA known as Causal Assessment or Stressor Identification (SI). This method can be used to help identify the cause(s) of biological impairment, such as the decline in a population of fall run salmon that has been observed in Dry Creek. Stressor Identification is based on principles of human epidemiology that identify associations between hypothesized causes and biological effects. Data is evaluated, using a pre-defined set of criteria, to determine the likelihood that any particular stressor might be responsible for the impairment. These criteria are used to systematically and consistently weigh the evidence. The EPA has developed a website (www.epa.gov/CADDIS) that presents information on Causal Analysis/Diagnostic Decision Information System, or CADDIS, that summarizes this approach and provide numerous supporting documents and information. OEHHA used CADDIS as the foundation for the causal analysis of the Dry Creek watershed.

CAUSAL ASSESSMENT STEPS

1. Define the case: Defining the case refers to clearly identifying the subject of the analysis. Initially, the biological alterations of concern must be identified. In the case of Dry Creek, a decrease in salmon abundance throughout the watershed or more generally, an impairment of aquatic life, was identified as the biological change of concern. Second, the geographical scope of the focus of the investigation must be determined. The focus of this investigation is the Dry Creek watershed, specifically, locations in the watershed where the impairment is most severe, technically referred to as **impaired**, as well as those places where the problem is less pronounced, referred to as the **internal reference or comparator site**. Linda Creek and Upper Cirby Creek were identified as the most impaired sites, while Upper Secret Ravine was identified as the comparator site. These sites were selected based on a review of data that reported on the condition of aquatic life. Lastly, the objective of the analysis should be clearly identified. In Dry Creek, our objective was to determine which stressors contribute most significantly to the impairment of aquatic life. Taken together, these three factors define the "case".

The key reason this analysis was undertaken was to understand why the population of anadromous fish in the watershed had fallen. However, salmon were not selected as the endpoint for this assessment because it was not possible to determine whether stressors in their freshwater or marine environments were responsible for the decline. Further, during the period of this study, the population of fall run salmon on along the entire West Coast was declining due to high ocean water temperatures, very low zooplankton in the oceans, and the delayed onset of upwelling[1] (Upwellings refer to the movement of water from deep in the ocean, usually rich in nutrients, as a result of winds blowing across the surface that pushes water away). In contrast to salmon that travel thousands of miles during their lifetime, benthic macroinvertebrates (BMIs), large larval and adult invertebrates that live in the streambed, are resident species that have been used for many years to assess water quality. Some of the more pollution-sensitive species of this large group share the same riffle habitat as salmon. Due to these factors and the availability of five years of BMI data, sensitive BMIs were selected as a surrogate for salmon.

2. Initial Screening of Candidate Causes. The initial screening involved reviewing all relevant data for each potential stressor to answer two questions: 1) Does a stressor response relationship exist between the stressor and various metrics of biological integrity (i.e., benthic macroinvertebrate or BMI data) and 2) Is there a relationship between the magnitude of the stressor under consideration and biological conditions at different sites? This second criterion is also referred to as spatial co-occurrence. If a stressor impacts the diversity and abundance of BMIs, then when the stressor is present at any particular location, aquatic life metrics should be poor whereas when the stressor is absent, aquatic life metrics should be better. In the particular case of Dry Creek, this meant comparing the relationships between stressors and BMI metrics at the comparator site, Upper Secret Ravine and the most impaired sites, Linda Creek and Upper Cirby Creek. Each stressor was screened using these two criteria. This screening included reviewing biological, physical, and chemical data and performing statistical analyses. Conceptual models were developed that illustrated the potential relationships between sources of stress (anthropogenic and/or natural sources); the physical, chemical, and biological stressors themselves; and their potential effects on aquatic life. OEHHA screened dozens of stressors (see Appendix to this chapter) and landscape metrics that might contribute to the impairment. When the result of the screening evaluation produced evidence that was weak, that stressor was eliminated from further consideration. If the results of this initial screening argued against these two criteria, that stressor was eliminated from further consideration. The candidate causes that were elevated for additional analysis were:

- Excess bedded fine sediment (elevated % silt, sand, and fine gravel)
- High turbidity (total suspended solids)
- Increased nutrients (nitrogen and phosphorus)
- Low levels of dissolved oxygen in the springtime
- Poor instream cover
- Low instream flow diversity (little variation in the depth and flow rate)
- Elevated temperature

3. Perform a detailed evaluation of data from the case: The data from the Dry Creek watershed on each of the likely stressors was carefully reviewed and scored. First, a "strength of the evidence" score, based on the consistency of relationships between the stressor and its effect on BMIs, was considered. The data from the initial screening was reviewed, examining the differences in biological integrity and each stressor at different sites (e.g. spatial co-occurrence) and the strength of the stressor-response relationship. A third criterion was also incorporated into the evaluation; the

1. Varanasi, U. and N. Bartoo. 2008. National Oceanic and Atmospheric Administration memo to D.R. Lohn and R.R. McInnis. Posted at: http://www.pcouncil.org/bb/2008/0308/D1b_SUP_NMFS.pdf .

evidence for a causal pathway. For each candidate stressor, causal pathways were diagrammed as a conceptual model to show relationships between sources of stress (landscape factors), proximate stressors, and degree of aquatic life impairment. For each of these three criteria, a "confidence" score was determined in addition to the strength of evidence score (see Table 1). The confidence score was based on data completeness, the qualitative or quantitative nature of the data, and other data quality considerations. The two scores were multiplied to produce a final score for the criteria. The evaluation of data from the case is described in greater detail in the Technical Section of this chapter.

4. Evaluate data from elsewhere: Data from elsewhere consisted of relevant data and reports from various locations within the watershed, peer-reviewed literature, and data from other watersheds. OEHHA used two criteria to evaluate the data: the existence of a mechanistically plausible cause and the identification of a stressor-response relationship. Data from elsewhere was only assigned a "strength of evidence" score, resulting in data from the case being weighted more heavily than from data from elsewhere.

STRENGTH OF EVIDENCE FROM THE CASE	SCORE	CONFIDENCE IN SCORE	FINAL SCORE (score*confidence)
Spatial co-occurrence or evidence of exposure	3	2	6
Stressor-Response relationship	5	3	15
Complete causal pathway	3	3	9
		SUB TOTAL	**30**
STRENGTH OF EVIDENCE FROM ELSEWHERE			
Plausible Mechanism	3		3
Stressor-response relationship	2		2
		SUB TOTAL	**6**
		GRAND TOTAL	**36**

Table 1. Sample Stressor ID score sheet used in the evaluation of potential Dry Creek stressors. Each stressor was evaluated for the overall strength of evidence with a score of 1 – 5. A confidence score, ranging from 1 – 3, was also assigned to reflect the confidence in the data and overall evaluation of each criterion.

5. Identify the probable causes: Step 5 involved summarizing the scores to determine the probable cause(s) of impairment. OEHHA summed scores from data from the case and from elsewhere to obtain a total score for each candidate cause. The total score for each stressor was normalized to 100, ranked, and then assigned to one of three categories of risk (low, moderate, high), based on the distribution of the scores. This categorical system for assessing risk was used to avoid attributing more precision to the scoring system than was warranted.

6. Assess the sources of stress: The CADDIS guidance identifies source analysis as a step that occurs outside of the formal Stressor Identification process (Figure 1). Although CADDIS does not provide specific guidance on how to identify sources of stress, they have developed an extensive module on urbanization and its effects on the aquatic ecosystem. Using this as a reference, OEHHA gathered existing landscape data from the watershed and generated new data as well. Literature on the relationship between landscape factors, spatial scale, and aquatic life was reviewed. All of this information was assessed using the same criteria as described above for the stressors (Steps 3 & 4).

7. Unresolved Stressors: There was a considerable amount of data that reported on potentially important stressors yet was limited in nature so it did not meet the criteria established for stressor identification review (Step 2 listed above). Potential stressors that fell into this category included:

- Pyrethroid pesticides
- Metals
- Altered hydrology/flashiness.

The types of data that were available for these stressors included reports prepared by consulting hydrologists, geomorphologist, or ecologist, containing valuable information of limited scope (e.g. a single site in the watershed) or observational data. In other cases, there were one-time data collection efforts within a limited geographical area which, in some cases, was not consistent with the established 10 study sites. To not review available data in any way would have given the impression that the stressor presented no risk at all. Yet, these potential stressors could have significant impacts on aquatic life. More data collected in a systematic fashion would be needed to definitely evaluate the risk. In these cases, we have identified the risk as “unresolved”.

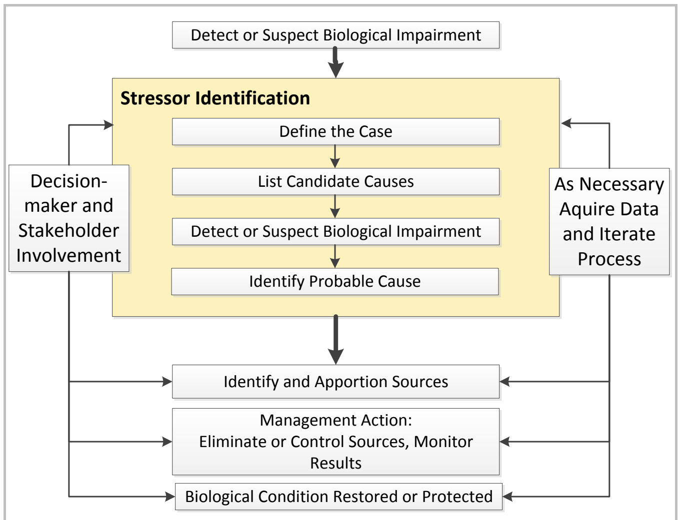

Figure 1. The Causal Assessment Conceptual Model. The Stressor Identification process is used to identify the most probably stressor(s) related to the impairment. Following this step, sources are identified and management actions taken to restore or rehabilitate the impairment in biological condition.

TECHNICAL CONSIDERATIONS

Additional information on the causal assessment process is reviewed in this section of the chapter.

INITIAL SCREENING

Potential stressors were eliminated from a detailed Stressor ID review for two reasons: insufficient or inadequate data or the lack two of both stressor response relationship and spatial co-occurrence. Data was screened for adequacy in three ways: 1) it was available for two-thirds of the sampling sites, 2) there was information for at least two years in August, September, and/or October so that it could be correlated with bioassessment metrics, and 3) there was a low frequency of non-detects (for chemical analyses). If data for any individual stressor met these three criteria, it was deemed adequate. If the potential stressor did not advance to full Stressor ID analysis due to a lack of data, however it was not necessarily removed from further review. In many cases, the data was evaluated and the potential stressor was classified as “unresolved” to indicate that additional data were needed to better understand its role as a potential stressor.

Secondly, if the data argued against a causal relationship, the stressor was eliminated from further analysis. Stressors with equivocal data were not eliminated. However, in cases where the data had no stressor response relationship (between the stressor and a biological effect) and/or data in which the spatial differences were the opposite of what one would expect, these stressors were eliminated from further consideration.

Evaluation of Data From The Case

Three criteria were used to evaluate data from the case, discussed in detail as follows:

1. Spatial Co-occurrence

Spatial co-occurrence refers to differences in the presence of the candidate cause and the effects at different sites in the watershed. This criterion was used to form the connection between cause and effect based on location. If an adverse response occurs only at those sites where the candidate cause is present, that evidence suggests that the potential stressor could cause the effect. Conversely, if the candidate stressor was present at all locations, regardless if an effect (e.g. adverse impact on BMIs) occurred or not, this would suggest that the candidate stressor was not responsible for the effect. In other words, if a stressor is responsible for the impairment, it will co-occur with the effect and vice versa. Figure 3 illustrates a situation where a presumptive contaminant in effluent killed fish downstream of the outfall but had no effect on upstream fish. This situation would strengthen the case that a contaminant in the effluent was a cause of impairment. If the fish living upstream and downstream of the outfall both appeared healthy, that evidence would weaken the case that something in the effluent was the cause of the fish kill. In this report, these relationships were evaluated using Spearman's R correlations with Bonferroni's adjustment to correct for risk of accepting differences as significant when they actually are not, a common problem when making multiple comparisons, and other non-parametric methods.

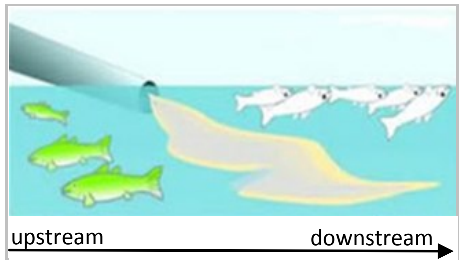

Figure 3. Example of spatial co-occurrence. Fish downstream of the effluent are dead while those upstream appear healthy. This evidence supports the case that a pollutant in the effluent is responsible for the impairment.

Example: Figure 4 shows instream cover scores at the 10 sampling sites in the watershed. Instream cover includes logs, boulders, and other objects which provide cover for aquatic life. Comparisons were made between the ten sampling sites, representing different sub-watersheds. If there were significant differences between the impaired (Sites 3 and 9) and comparator (Site 5) sites that were correlated with changes in sensitive BMIs, that would suggest a cause and effect relationship might exist. However, in this case, data from Sites 6 and 7 were similar to the comparator site. BMI metrics from Sites 6 and 7 suggested lower abundance and diversity than at Site 5 (comparator site). Weighing the evidence, this data did not clearly demonstrate spatial differences in the relationship between instream cover and BMI metrics.

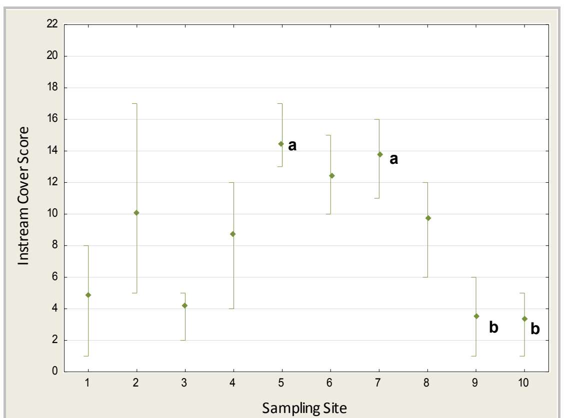

Figure 4. Variation in instream cover at different sampling sites. Letters indicate significant differences between sampling sites (Kruskal-Wallis test, $p < 0.05$).

2. Stressor-Response Relationship

The second criterion used in the evaluation of stressors was the strength of the stressor-response (S-R) relationship. A strong S-R relationship would suggest that the stressor could be a cause of the impairment. In Dry Creek, data from all sites were pooled to determine if a stressor-response relationship existed between any one explanatory variable (i.e., a stressor) and any of the BMI metrics that were analyzed. Having a greater proportion of BMI metrics significantly correlated in the expected direction with the candidate stressor would strengthen the case for that stressor as a cause of the impairment (Figure 5). Spearman's rank correlations, quantile regression, and other non-parametric methods were used to determine the significance of these relationships.

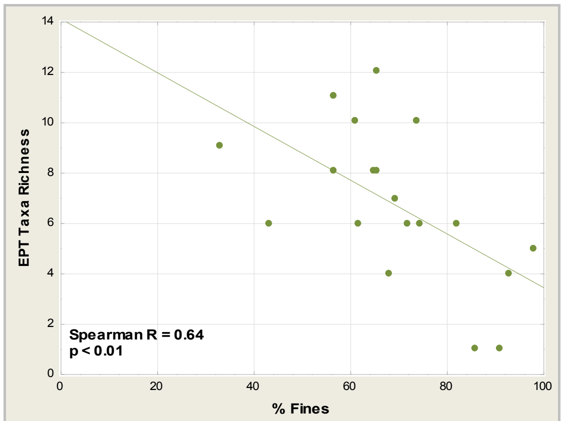

Figure 5. Biological response to fines in the streambed. EPT taxa are a group of benthic macroinvertebrates generally more sensitive to pollution and disturbance than most other BMIs. As the percentage of fine particles in their habitat, riffles in the streambed, increased, the number of EPT taxa declined. About 40 % of the BMI metrics were strongly, consistently, and negatively correlated with fine sediment in the streambed, therefore strengthening the case that fine sediment as a likely cause of impairment of aquatic life.

3. Complete Causal Pathway

The third criterion, the identification of a causal pathway, is based on verifying the linkages between the potential cause of the impairment and the effect. Figure 6 illustrates a situation where effluent containing nutrients was released into a waterway, resulting in an algae bloom. During the night, when plants produce energy via respiration, oxygen is consumed, reducing the concentration of dissolved oxygen in the water to low levels. Once the algae dies, the decomposition process also consumes oxygen. The resulting anoxic conditions caused a fish kill. Data linking nutrient input, the presence of an algae bloom, low dissolved oxygen, and a fish kill forms the complete causal pathway.

The conceptual model (Figure 7) illustrates a complete causal pathway between increased impervious cover, decreased sediment sources, increased bank incision, reduced sediment size, reduced stream habitat diversity, and reduced BMI diversity and abundance. Data for each step in the pathway was either available or generated by OEHHA. The strength of correlation (Spearman's R) between each step, the number of years of data, the nature of the data (e.g., qualitative or quantitative), and the number of steps for which data were available; all of these factors were considered when determining the strength of this line of evidence.

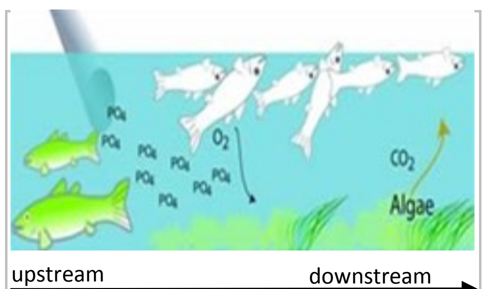

Figure 6. Complete causal pathway

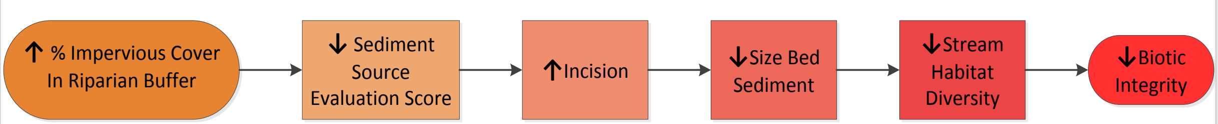

Figure 7. Fine in the streambed conceptual model.

Evaluation of Data from Elsewhere

Peer-reviewed studies and reports were examined to evaluate the plausibility of the proposed relationship between any one stressor and the effects on aquatic life. This process included a review of the scientific literature as well as a review of special one-time or special studies within the Dry Creek watershed. There were multiple surveys of aquatic and riparian habitat dating back to the mid-1990s that also provided valuable information. Two criteria were used to evaluate evidence from other situations:

- Mechanistically plausible cause: Does outside evidence support a scientific, established causal pathway analogous to the one observed from the case?
- Stressor-response relationship: At what concentration or level of a stressor is a biological response observed in the literature. Are observed levels environmentally relevant?

Evaluating data from elsewhere helped to strengthen or weaken the case for a stressor as the cause of the impairment.

The Scoring Process

Details of the criteria used for scoring are listed in the appendices to this chapter. Briefly, data from the case was given a ranking of 1 – 5 based on the strength of evidence for the three key criteria. Factors such as the consistency of the differences in response between sampling sites, the strength of the stressor-response relationship, and the number of intermediates in a causal pathway that could be documented with watershed data, were considered in assigning a score. Confidence in the data was evaluated using a ranking of 1 – 3, based on quality and quantity of the data. The two scores were multiplied to produce a final score for each criterion. Data from elsewhere was treated in a similar fashion but not assigned a confidence score. Once completed, the scores were summed and low, moderate and high risk groups were identified to reflect the likelihood a stressor could contribute to the impairment in aquatic life (refer to Table 1 of this report).

Technical Information on the Data

Data available included many physical habitat, water/sediment quality, and biological metrics collected by the Dry Creek Conservancy, as well as sediment quality, toxicity, geomorphic and landscape data generated by OEHHA. The PHAB (physical habitat) metrics included those in the 2006 SWAMP (Surface Water Ambient Monitoring Program) protocols. A wide range of water quality data including pesticides, volatile and semi-volatile organics, and metals were analyzed in water samples. Yearly assessments of benthic macroinvertebrate abundance and diversity covering a 5 year period were performed as well as ten years of fall-run chinook salmon counts. A summary of all data used in the analysis can be found in Table 2.

Table 2. List of watershed data, the source, and the years of data that were available.

Source	Indicator Type	Metric	Years of data
Dry Creek Conservancy	Effect	Fall-run chinook salmon fish counts (live fish, carcasses, redds)	18
		Benthic macroinvertebrate measures	5
	Water quality (from grab samples)	Temperature	2 - 4
		Dissolved oxygen	2 - 4
		Total Suspended Solids	2 - 4
		pH	2 - 4
		Specific conductance	1 - 4
		Ammonium	1 - 4
		Nitrate	1 - 4
		Orthophosphate	1 - 4
		Chemical Oxygen Demand	2 - 4
		Alkalinity	2 - 4
		Copper	2 - 4
		Zinc	2 - 4
		Lead	2 - 4
	Water quality (from continuous sampling)	Temperature	2
		Dissolved oxygen	2
		Total Suspended Solids	2
	Stressor (Physical Habitat)	Epifaunal substrate (Instream cover)	5
		% Embeddedness	5
		Sediment deposition	5
		Channel Alteration	5
		% Canopy Cover	2
		Vegetative Cover	3
		Bank Stability	3
		Velocity/depth regime (Instream Flow Habitat)	3
		Channel Flow Status	3
OEHHA	Source of Stress	Land uses	1
		Impervious cover	1 -2
	Stressor (Water/Sediment Quality)	Metals	1
		Pyrethroids	1
	Stressor (Physical Habitat)	% Silt, Sand, Fine Gravel	2
City of Roseville	Stressor (linked to flashiness analysis)	Precipitation	11
USGS	Stressor (flashiness)	Flow	11

Causal Assessment Methodology

The following two tables describe the criteria used for evaluating stressors and their sources using data from the case and elsewhere.

Table 3a. Assessment and scoring of data from comprehensive studies in the Dry Creek watershed. Only stressors with a minimum of 3 years of data from at least 9 of the 10 sampling sites were evaluated with these criteria. The score for each criterion was determined by multiplying the strength of evidence score by the data confidence score, then the three scores were summed to get the total score for data from the case.

Criteria	Factor	Score	Description
Spatial Co-occurrence	Strength of Evidence	5	Strong evidence; Effects consistently seen when candidate cause present and not seen when candidate cause not present. Greatly strengthens the case.
		4	Effects seen when candidate cause present and not seen when candidate cause not present, few inconsistencies in relationships between comparator, impaired, and other tests sites in the watershed. Strengthens the case.
		3	Spatial relationship between effects and candidate cause observed but consistencies seen and statistical relationships of marginal significance. This condition neither strengthens nor weakens the case
		2	Relationships between effects and candidate cause observed but with many inconsistencies. This condition weakens the case.
		1	Inconsistent relationships seen between effects and candidate cause at comparator and impaired sites. Refutes the case.
	Confidence in Data	3	High quality data, quantitative in nature, for multiple years (typically 5+).
		2	Moderate quality data, some qualitative data, for fewer years (3-5 years).
		1	Lower quality data, much of it qualitative, for fewer years (3-5 years).
Stressor Response Relationship	Strength of Evidence	5	Strong and consistent stressor response relationships, high degree of statistical significance, gradient in expected direction. Greatly strengthens the case
		4	Many significant relationships, but not as strong and statistically significant as for 5. Gradient in expected direction. Strengthens the case
		3	Some significant relationships, gradient in expected direction, but inconsistent across all sites. Data is equivocal.
		2	Inconsistent relationships between stressor and effect. Gradient not always as expected. Many outliers. Weakens the case.
		1	No consistent relationships. Refutes the case.
	Confidence in Data	3	High quality data, quantitative in nature, for multiple years (typically 5+).
		2	Moderate quality data, some qualitative data, for fewer years (3-5 years).
		1	Lower quality data, much of it qualitative, for fewer years (3-5 years).
Complete Causal Pathway	Strength of Evidence	5	Data from the watershed shows that most steps in one or more causal pathways exist. Greatly strengthens the case.
		4	**Some** steps in at least 1 causal pathway are present. Strengthens the case.
		3	Most steps in the pathway are **uncertain** due to lack of data or weak relationships**.** Data is equivocal.
		2	Many steps in causal pathway missing due to lack of relationships. Weakens the case.
		1	Most steps in pathway show no relationship to cause or effect. Refutes the case.
	Confidence in Data	3	Great deal of quantitative data used to verify steps in pathway
		2	Some quantitative data used to verify some steps in pathway
		1	Little quantitative data or anecdotal information available to verify steps in pathway.

Table 3b. Assessment and scoring of data from one-time studies and the literature (data from elsewhere). Data from the scientific literature was evaluated using the criteria identified in the table. In some cases, one-time studies or studies conducted in a single sub-watershed within Dry Creek were conducted. These studies were evaluated using the above criteria as well. A confidence score was not use to assess the quality of the data because literature had already been subjected to peer review. By not including a data quality score in this ranking process, the literature and one-time studies were not given as much weight as multi-year studies of the entire watershed.

Criteria	Evaluation Factor	Score	Description
Stressor Response Relationship	Strength of Evidence	5	Strong and consistent stressor response relationships identified in numerous studies. If data from one-time studies exists, gradient in the expected direction. Greatly strengthens the case
		4	Most literature supports S-R relationships. Gradient in expected direction. Strengthens the case
		3	Inconsistent results from one-time or studies from the literature. Neither strengthens nor weakens the case.
		2	Most studies do not support the expected S-R relationship. No one-time studies within the watershed. Weakens the case.
		1	Literature completely lacking or no relationships found between possible cause and impairment. Refutes the case.
Complete Causal Pathway	Strength of Evidence	5	Data clearly identifies a causal pathway. Strongly supports the case.
		4	Data lends some support to a causal pathway. Supports the case.
		3	Data from one-time studies is ambiguous but data from the literature provides support. Neither refutes nor confirms a causal pathway.
		2	Data from one-time studies and the literature is ambiguous. Weakens the case.
		1	Both data from one-time studies and literature do not support the causal pathway. Refutes the case.