WORK PLAN

Predicting Biological Integrity of Streams Across a Gradient of Development in California Landscapes

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Introduction

The California State Water Resources Control Board (State Water Board) is developing a combined Biostimulatory (nutrient) and Biointegrity policy for wadeable streams, hereto referred to as the Biostimulatory-Biointegrity Project. The scientific approach supporting this project is grounded in biological assessments of the health of benthic macroinvertebrate and algal communities. The State is supporting the use of standardized bioassessment indices to quantify the biological integrity and support of aquatic life uses in wadeable streams. The benthic macroinvertebrate index (i.e., the California Stream Condition Index, or CSCI) has previously been developed (Mazor et al. 2016). An algal stream condition index (ASCI) is currently under development, with a provisional ASCI expected fall 2017 (see ASCI workplan, Theroux et al. 2016).

As landscapes converted from natural to urban or agricultural uses, the underlying hydrologic, physical, and biogeochemical factors within the stream and its catchment that support healthy stream communities are altered, potentially harming aquatic life. Developed landscapes are associated with an increase of many stressors in streams, such as elevated contaminant and nutrient concentrations, altered flow regimes, sedimentation, and habitat degradation (e.g., Waite et al. 2012). In some streams, direct channel modifications (e.g., bank armoring) may also limit opportunities to sustain high-quality ecological conditions for aquatic life. In these highly developed settings, the large number of linked stressors may prevent a stream from supporting its beneficial uses or attaining high scores on indices of biological condition. Often, these stressors are difficult to mitigate or remove under the traditional mechanisms available to the Water Boards. In these circumstances, the range of CSCI and/or ASCI scores may be constrained, but targeted restoration could improve conditions. Key technical questions underpinning the range of options and prioritization of management actions for wadeable streams along the continuum from undeveloped to highly developed landscapes found within California are: For which streams is biological integrity constrained by development in the catchment? How can they be identified and mapped? What are the ranges of conditions they can support?

The State Water Board is seeking to protect biointegrity in streams, including streams where integrity is constrained by development. Identifying landscapes where development has a high likelihood of limiting biointegrity is an important first step to identifying effective management options. This creates a technical need for 1) a simple, reproducible, and easy-to-understand methodology for identifying landscapes where development has a high likelihood of limiting biointegrity and 2) predicting expectations for CSCI and (when available) ASCI indices. These analyses create a technical foundation for the State Water Board and the Regional Boards to protect biological integrity in streams by informing appropriate expectations or by prioritizing sites long and short term restoration activities in these landscapes.

Geographic information systems (GIS) are commonly used to quantify landscape development within stream catchments. Estimating landscape alteration in catchments has traditionally been time-consuming for large-scale programs that monitor hundreds of sites annually, but recent tools (i.e., STREAMCAT, Hill et al. 2015) have made it possible to rapidly estimate landscape alteration in all streams in California represented by the National Hydrography Dataset Plus (NHD Plus) stream network. STREAMCAT therefore presents an opportunity to model the influence of landscape alterations on stream bioassessment scores on a large scale, and to apply predictions of these models to any stream represented in NHD Plus. These models have the potential to predict a range of likely scores in a stream given a degree of landscape alteration, setting the stage for policy discussions about the level of support that these streams in developed landscapes provide to beneficial uses.

Study Objective, Conceptual Approach to Model Landscape Influences on Stream Bioassessment Index Scores

The purpose of this study is to explore constraints on bioassessment index scores in streams across a continuum of landscape development, using a GIS approach. Key graphics from this analysis will be used to support discussions between the Water Board and its Regulatory and Stakeholder Advisory Groups on policy options to prioritize and improve the management of streams in developed landscapes.

The GIS approach involves developing models that predict a range of bioassessment index scores based on measures of landscape development. The product of these models is a map of likely CSCI (and when available, ASCI) scores for each segment. The intent of such a map is to identify watersheds where discussions of policy options for undeveloped versus developed landscapes could be productive. This map is intended to be used as a screening tool or starting point for discussions; it is not intended to be a one-off, definitive assessment that is used to set expectations for developed landscapes without further field level investigations.

This approach relies on the following definition of “developed landscapes”:

> *Landscapes where development is likely to limit bioassessment index scores.*

Development of a GIS model and application to the predict likely bioassessment index scores in developed landscapes require three types of decisions:

1. *Developed Land Uses*. Developed landscapes can be characterized by variables in the STREAMCAT dataset related to human alterations, such as urban and agricultural land-use

types in the National Land Cover Dataset, land cover imperviousness, etc. (Table 1). Other variables could be included or excluded, but must be limited to variables included in or easily added to STREAMCAT.

2. *Likelihood*. The likelihood of achieving the desired biological condition can be calculated by statistical models, but determining if a likelihood is low enough to be considered "unlikely" is a value-based (i.e., non-technical) decision.
3. *Desired biological condition:* The management objective, as defined by bioassessment index scores, here to referred to as "assessment endpoints" (Sutula et al. 2017, Bio-integrity-Biostimulatory Project Science Plan).

Decisions on which developed land variables to include must occur during model development, while discussion of values appropriate to set the likelihood and desired CSCI and ASCI assessment endpoints are model application question, all of which will ultimately be made by the Water Board. In order to foster discussion and provide the regulatory (RG) and stakeholder advisory groups (SAG) an opportunity to provide feedback on these three decisions, the Technical Team will iteratively engage the RG and the SAG in the model development and model application phases to provide ample opportunity for this feedback to occur.

Scope of Work:

The study has three tasks:

1) Develop a model to predict a range of CSCI and ASCI scores based on measures of landscape development from the STREAMCAT dataset;
2) Apply the models to the entire NHD Plus stream network represented in the STREAMCAT dataset, classify stream segments based on likelihood of achieving target scores, and create maps illustrating these classifications, in order to engage Water Board staff and advisory groups on decisions on likelihood and CSCA and ASCI assessment endpoints; and
3) Produce a technical memo with key graphics and model output.

Task 1. Develop models to predict a range of CSCI and ASCI scores based on measures of landscape development derived from the STREAMCAT dataset

A dataset representing CSCI scores from across a range of site conditions in California will be aggregated. Index scores from each site will be snapped to the corresponding stream segment in NHD Plus. STREAMCAT data characterizing landscape alteration variables (e.g., percent urban land cover, percent cropland, catchment imperviousness; Table 1) will be associated with each bioassessment site. Appropriate statistical models (e.g., quantile random forest) will be calibrated to associate measures of landscape development with bioassessment scores. Models will also be developed for ASCI index scores, though decisions on which land use variables and likelihood values to use will focus on CSCI only, since a provisional ASCI index is anticipated late stage (Fall 2017).

Water Board staff will make provisional decisions on land use variables to include. The initial proposal will be based on consultation with the RG. The proposed land use variables and rationale will be presented to the SAG for feedback.

Deliverable:

1.1 Draft models and related graphics to predict bioassessment scores, in iterative stages of feedback.

1.2 Descriptive summaries of models, including evaluations of model performance, and list of landscape development variables in STREAMCAT selected for use in the models.

Table 1. List of STREAMCAT variables that can be evaluated in landscape modeling exercise. Most of these variables are calculated at multiple spatial scales.

Potential variables	Description
CanalDens	Density of NHDPlus line features classified as canal, ditch, or pipeline (km/ square km)
DamDens	Density of georeferenced dams (dams/ square km)
DamNrmStor	Volume all reservoirs (NORM_STORA in NID) per unit area (cubic meters/square km)
HUDen2010	Mean housing unit density (housing units/square km)
MineDens	Density of mines sites and within 100-m buffer of NHD stream lines (mines/square km)
PctAg2006Slp10	% area classified as ag land cover (NLCD 2006 classes 81-82) occurring on slopes ≥ 10%
PctAg2006Slp20	% area classified as ag land cover (NLCD 2006 classes 81-82) occurring on slopes ≥ 20%
PctCrop2006	% area classified as crop land use (NLCD 2006 class 82)
PctHay2006	% area classified as hay land use (NLCD 2006 class 81)
PctImp2006	Mean imperviousness of anthropogenic surfaces
PctUrbHi2006	% area classified as developed, high-intensity land use (NLCD 2006 class 24)
PctUrbLo2006	% area classified as developed, low-intensity land use (NLCD 2006 class 22)
PctUrbMd2006	% area classified as developed, medium-intensity land use (NLCD 2006 class 23)
PctUrbOp2006	% area classified as developed, open space land use (NLCD 2006 class 21)
PopDen2010	Mean populating density (people/square km)
RdCrs	Density of roads-stream intersections (2010 Census Tiger Lines-NHD stream lines) (crossings/square km)
RdDens	Density of roads (2010 Census Tiger Lines) (km/square km)

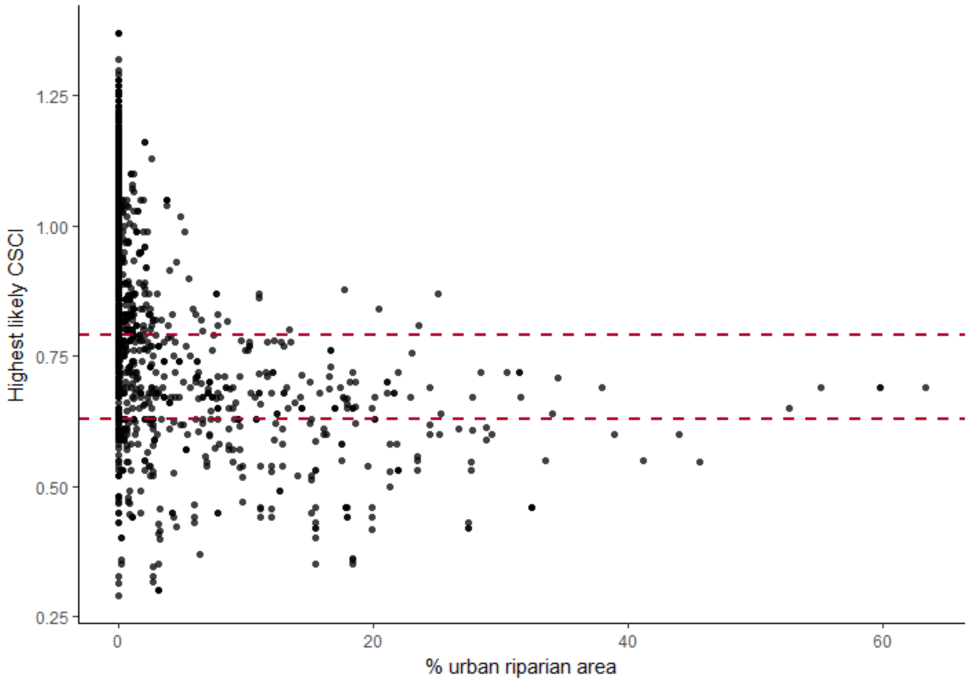

Figure 1. An example of the highest likely CSCI scores predicted by a quantile random forest model relating developed land use variables to biological integrity. The x-axis is percent of high density urban land cover within a 100-m buffer around the NHD stream lines (one of the variables included in example model). Dots above the top red line represent sites that are unconstrained by development (in this example, >10% chance of CSCI scores > 0.79). Dots between the two red lines are moderately constrained by development (<10% chance of CSCI scores > 0.79). Dots below the bottom red line are highly constrained by development (<10% chance of CSCI scores > 0.63). In this example, the 90th percentile of predicted scores represents the highest likely CSCI score.

Task 2. Apply the models to engage Water Board staff and advisory groups on discussions of sensitivity of model output to choice of likelihood and assessment endpoint

The purpose of this task is to help State Water Board staff and advisory groups understand how choice probabilities used to define modeling likelihood and desired assessment endpoint affects mapped categories of streams. The GIS mapping methodology will be applied to entire NHD Plus network of streams in California included in the STREAMCAT database. For selected regions or watersheds, the influence of key decision-points (e.g., minimum thresholds for acceptable bioassessment index scores, or minimum acceptable likelihood for attainment of these thresholds) will be illustrated by to showing how the decisions described above influence the percentage and spatial extent of the stream network within the developed category. For example, the Water Board may define constrained channels as those with less than a 10% chance to achieve a CSCI score above 0.63 (e.g., dots below the bottom dashed line in Figure 1); maps will then be generated to highlight which streams are designated as constrained under this definition, thereby helping stakeholders see the implications of this classification for their watersheds (e.g., segments shown as red lines in Figure 2).

Deliverable: 2.2 Interactive maps and oral presentations with maps, graphics, summary tables of the stream drainage network showing model outputs, e.g., maximum score likely to be attained in each stream segment (Figures 2 and 43 as a function of choice of likelihood and assessment endpoint value.

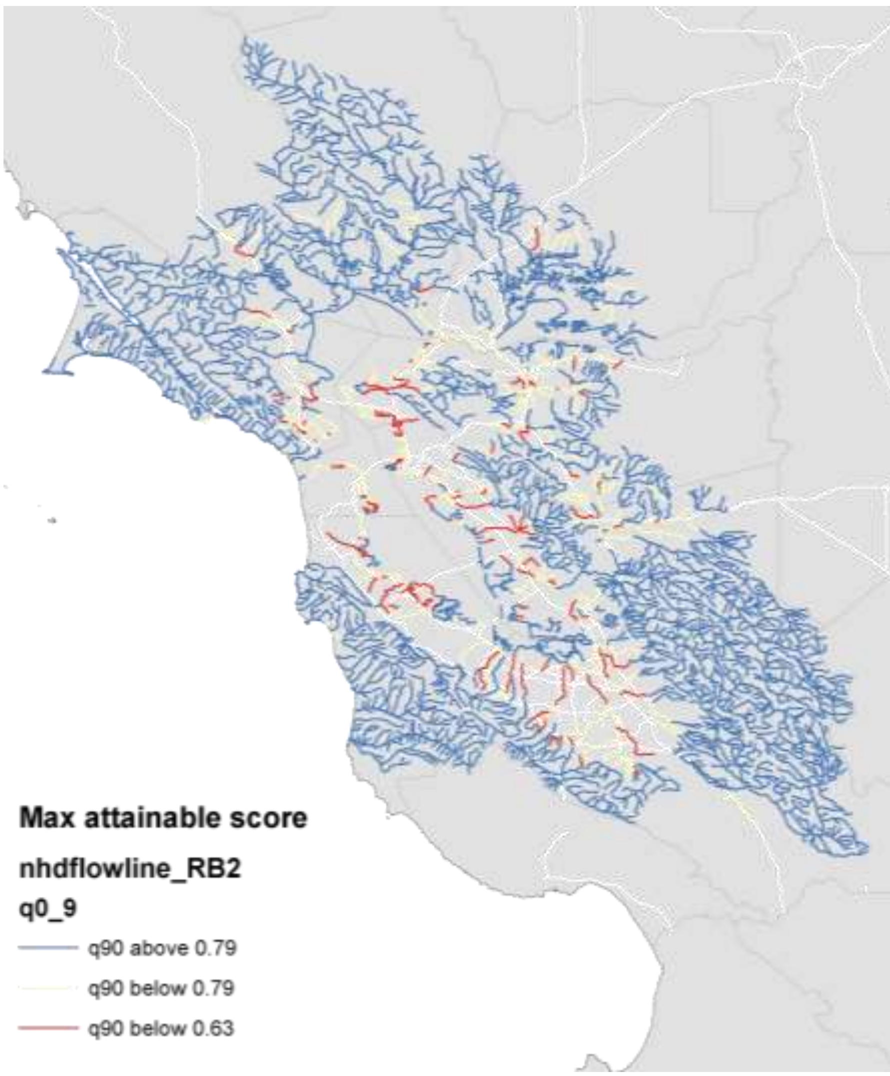

Figure 2. Map showing the classification of stream segments in the San Francisco Bay Area based on landscape development. In this map, attainability is defined as the 90th percentile of model predictions for each segment. Blue segments: Unconstrained by development, as described in Figure 1. Yellow segments: Moderately constrained by development. Red segments: Highly constrained by development.

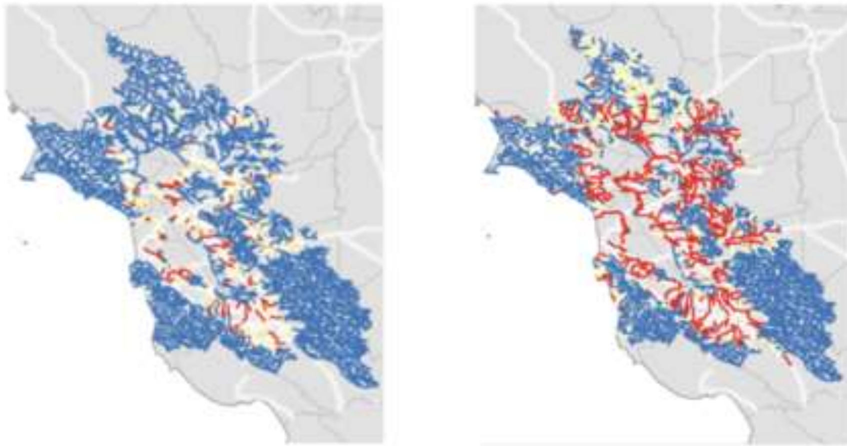

Figure 3: Example of maps generated with two different probabilities to define likelihood. The map on the left was generated with a 10% probability to define likely scores, whereas the map on the right was generated with a 50% probability.

Task 3. Produce a Technical Memo with Key Graphics and Model Output

Based on feedback from group discussions and Water Board direction from Task 2, a reduced set of interactive maps and graphics can be generated to support this discussion. The purpose of this task is produce a technical memo with this reduced set of key graphics and model output in a format that can be easily shared and used to support discussions among Water Board staff and its advisory groups on policy options for channels in developed versus undeveloped landscapes. The maps and graphics will include ASCI scores and a linkage to Biological Condition Gradient calibration (see BCG workplan), and versions of maps and graphics to demonstrate policy options under consideration, as requested by Water Board staff.

Deliverables: 3.1) technical memo summarizing methodology and results of task 1 and 2, 3.2) model output that can be viewed in an interactive mode (e.g. Google Earth kmz file), 3.3) Presentation to RG and SAG of illustrating policy options under consideration, upon request of Water Board staff.

Schedule of Interim Milestones and Deliverables

Task	Description	Estimated Date
1.1	Draft models and related graphics to predict bioassessment scores, in iterative stages of feedback	May 2017 (CSCI) September 2017 (ASCI)
1.2	Descriptive summaries of models, including evaluations of model performance, and list of landscape development variables in STREAMCAT selected for use in the models.	May 2017 and iteratively thereafter
2.2	Interactive maps and oral presentations with maps, graphics, summary tables as a function of choice of likelihood and assessment endpoint value.	May 2017 and iteratively thereafter
3.1	Draft and final technical memo summarizing methodology and results	September 2017 December 2017

3.2	Interactive model output (e.g. google earth .kmz file)	September 2017 December 2017
3.3	Presentation to RG and SAG of illustrating policy options under consideration	Upon request by Water Board staff

Citations

Hill, R.A., M.H. Weber, S.G. Leibowitz, A.R. Olsen, and D.J. Thornbrugh. 2015. The Stream-Catchment (StreamCat) dataset: A database of watershed metrics for the conterminous United States. Journal of the American Water Resources Association 52: 120-128.

Mazor, R.D., A.C. Rehn, P.R. Ode, M. Engeln, K.C. Schiff, E.D. Stein, D.J. Gillett, D.B. Herbst, and C.P. Hawkins. 2016. Bioassessment in complex environments: Designing an index for consistent meaning in different settings. Freshwater Science 35(1): 249-271

Waite, I.R. J.G. Kennen, J.T. May, L.R. Brown, T.F. Cuffney, K.A. Jones, and J.L. Orlando. 2012. Comparison of stream invertebrate response models for bioassessment metrics. Journal of the American Water Resources Association 48: 570-583.