From:	Yeager, Matt
To:	sandiego
Cc:	Boon, Richard J; Quinonez, Edwin; Guill, Rebekah
Subject:	“825417: Comment – Administrative Draft of Proposed Basin Plan Amendment to Incorporate Biological Objectives, Attn: Chad Loflen
Date:	Thursday, February 22, 2018 6:22:22 PM
Attachments:	Comment Letter - 825417 Administrative Draft of Proposed Basin Plan Amen....pdf Comment Letter Attachments - 825417 Basin Plan Amendments, Biological Ob....pdf

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Hello,

Please accept the attached comment letter and attachments regarding the Administrative Draft of the proposed Basin Plan Amendment to incorporate Biological Objectives.

Sincerely,

Matt

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RIVERSIDE COUNTY FLOOD CONTROL
AND WATER CONSERVATION DISTRICT

February 23, 2018

Sent via Email to: SanDiego@waterboards.ca.gov

Mr. Chad Loflen
CRWQCB – San Diego Region
2375 Northside Drive, Suite 100
San Diego, CA 92108

Dear Mr. Loflen

Re: 825417: Comment – Administrative Draft of Proposed Basin Plan Amendment to Incorporate Biological Objectives

The Riverside County Flood Control and Water Conservation District (District) appreciates the opportunity to provide comments on the Administrative Draft of a Proposed Basin Plan Amendment to the Water Quality Control Plan for the San Diego Basin to Establish Biological Water Quality Objectives (proposed Biological Objectives). District staff attended the public workshop for the proposed Biological Objectives on February 14, 2018, at the San Diego Regional Water Quality Control Board (San Diego Water Board) and provided brief oral comments. As requested by the San Diego Water Board Chair, we are providing more detailed comments described below.

Biological Assessments Should Be Used For Prioritization

The District generally supports the concept of biological assessments as an improved measure of watershed health as compared to physical and chemical measures alone. Characterization of biological conditions for streams could allow watershed managers to identify streams that are particularly healthy, average, or less healthy, and prioritize them for preservation or rehabilitation based on available resources. In particular, the District supports an approach which includes consideration of the actual, achievable biological condition of stream environments whether minimally impacted or as modified by intense urbanization. The State Water Board is currently considering precisely this approach in its Biostimulatory/Biointegrity Plan (State Biointegrity Plan) development through a project entitled Expert Interpretation of the Biological Condition Gradient in California Wadeable Streams or "BCG."[1] This approach is also supported by scientific experts in the Pacific Northwest, Australia, and has been used to set biological objectives for five states (Maine, Florida, Pennsylvania, Minnesota, and Connecticut) in the United States.[2,3]

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[1] Raphael Mazor: Constraints on biological integrity in streams in developed landscapes. Presentation to the State Water Board Science Panel for Biostimulatory and Biointegrity Project, April 19, 2017.

[2] Smith, RF; Hawley, RJ; Neale, MW; Vietz, GJ; Diaz-Pascacio, E; Herrmann, J; Lovell, AC; Prescott, C; Rios-Touma, B; Smith, B; and Utz, RM: "Urban stream renovation: incorporating societal objectives to achieve ecological improvements," Freshwater Science 35, no. 1 (March 2016): 364-379

[3] Hughes, RM; Dunham, S; Maas-Hebner, KG; Yeakley, JA; Schreck, C; Harte, M; Molina, N; Shock, CC; Kaczynski, VW; and Schaeffer, J: A review of Urban Water Body Challenges and Approaches (1) Rehabilitation and Remediation. Fisheries: 39(1) 2014, Pages 18 – 29.

In contrast to the emerging regulatory consensus represented by the State Water Board's approach, the proposed Biological Objectives set a single priority for the entire region that all streams should be restored to reference-analogous conditions. One certain result from the proposed Biological Objectives will be numerous new impaired stream segments on the 303(d) list—among them will be many existing flood control facilities that are actively providing protection of life and property from floods and local water supply augmentation benefits with no clear approach for ever achieving the required biological conditions within these facilities. The proposed objectives and the Staff Report show that such modified channels will end up on the impaired list.

Therefore, the District finds that the proposed Biological Objectives create a regulatory mandate that conflicts with its core mission objectives and legislatively authorized activities. The District was created by an act of the State Legislature on July 7, 1945 (Chapter 1122; Statutes of 1945; Act 6642) with the basic Flood Control District mission objectives (excerpted from Act 6642—emphasis added):

> "…**to protect people, property and watersheds from damage or destruction** from flood and storm waters and to conserve, reclaim and save such waters for beneficial use."

The District has been authorized by the State Legislature:

a. "…to ***control*** the flood and storm waters of the district…"
b. "...to conserve these waters for beneficial and useful purposes within the district by ***retarding, spreading, storing, retaining*** and causing to percolate into the soil…"
c. "…to ***save and conserve in any manner all or any of the waters and protect from damage from these flood or storm waters the watercourses, watersheds, public highways, life and property…***"

Flood control conveyances have been deemed essential to achieve the mission of the District. Flood control facilities that have been legally funded and constructed consistent with all required federal, state, and local regulatory authorizations and permits, and which include concrete and other structural materials which do not and were not designed to support a biological community, simply will not meet the proposed narrative or numeric objectives. In order to ensure hydraulic capacity and the design standard of flood protection, such engineered and hardened conveyances also require regular maintenance. Such maintenance requires the removal of excess sediment and plant materials that interfere with the hydraulic functions. Therefore, the establishment of a biological community analogous to undisturbed watershed conditions within these systems conflicts with the intended, essential, and legally authorized purpose of these facilities. In fact, failure to maintain flood control capacity in these facilities creates significant legal liability for the District.

As a recent example of what is required to "protect from flood damage," the District is a partner in the Murrieta Creek project: a multi-purpose flood control, environmental restoration and recreation project along 7.5 miles of Murrieta Creek, tributary to the Santa Margarita River. The project's major features include about seven miles of channel improvements, three bridge replacements, a 270-acre detention basin with 163 acres of wetland restoration and a 49-acre recreation park (USACE Website:

http://www.spl.usace.army.mil/Media/News-Stories/Article/620445/work-on-murrieta-creek-project-begins/). This project will cost approximately $167 million and will require over 20 years to complete. It incorporates significant environmental features and habitat-friendly designs requires the District to maintain a total of 233 restored acres. Even so, stream reaches within this project would likely not meet the proposed narrative or numeric biological objectives. This is evidenced by information developed by the State Biointegrity Plan project called Predicting Biological Integrity of Streams Across a Gradient of Development in California Landscapes, or "Developed Landscapes Project". This project involved modeling to predict which CSCI scores are possible in a waterbody given a range of potential constraints represented by GIS based land use characteristics (accessed from STREAMCAT database). The model can predict the range of CSCI scores that are likely for given sites and can also predict the probability of achieving a particular CSCI score.

The predicted model results are shown in Figure 1 for the Upper Santa Margarita River watershed. The red streams are likely constrained and have a less than 10% chance of scoring above the proposed 10th percentile numeric objectives (0.79). The pink streams are possibly constrained. Most of the District's facilities and Murrieta Creek where the restoration is located are located in a possibly constrained or likely constrained waterbody. This means that meeting the proposed numeric biological objectives, even with restoration, is not likely given the surrounding land uses and modified channels.

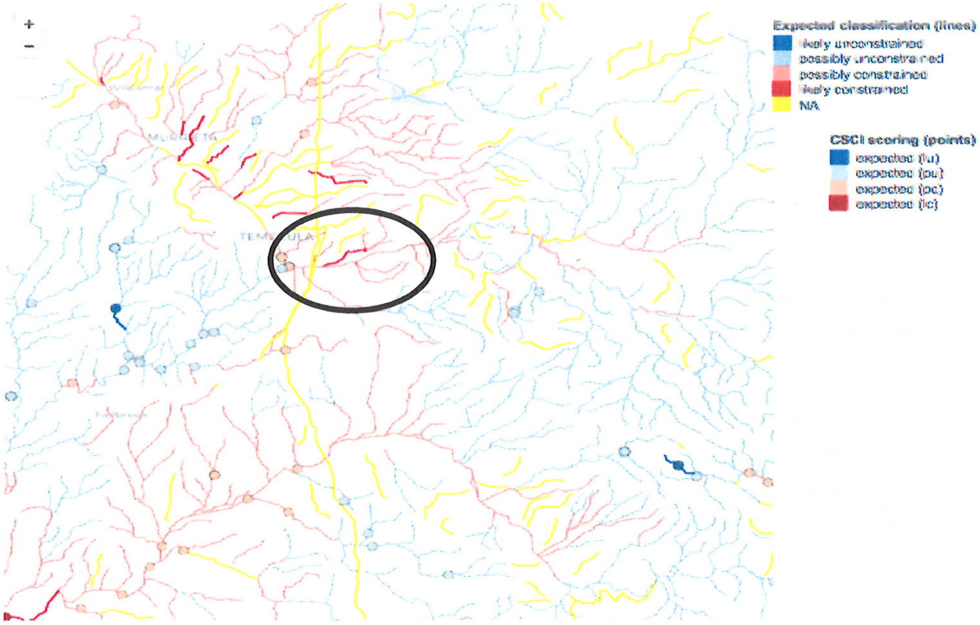

Figure 1. Map of Potential Constraints on Biological Condition in Upper Santa Margarita River Watershed based on Developed Landscapes Tool.[4] Murrieta Creek Project area is circled.

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[4] Map generated from https://beckmw.shinyapps.io/biological_constraints/. Website created by SCCWRP.

The Proposed Objectives are not Reasonable as Required by the California Water Code

The California Water Code, Section 13000 requires that: "... activities and factors which may affect the quality of the waters of the state shall be regulated to attain the highest water quality which is **reasonable, considering all demands being made and to be made on those waters and the total values involved, beneficial and detrimental, economic and social, tangible and intangible.**" (Emphasis added.)

The District believes the proposed narrative objective is not achievable in all streams in the region and; therefore, not reasonable. For reference, the proposed narrative objective presented at the CEQA Scoping Workshop on July 28, 2016 was:

> "Waters of the State shall be of sufficient quality to support native aquatic species without detrimental changes in the resident biological communities."
> However, the current proposed narrative objective is:
>
> "Surface waters within the San Diego Region shall support an ecologically balanced and resilient community of organisms having a native species composition, diversity, abundance, and functional organization commensurate with that of unaltered analogous waters."
>
> The added requirements for "...native species composition" and "...commensurate with that of unaltered analogous waters," mean that the proposed narrative objective would set a standard equivalent to virtually no anthropogenic impact.

The District believes the current proposed narrative objective includes the false premise that waters "shall support" the requisite biological condition. The narrative must be limited to a requirement for water quality alone. The CEQA scoping narrative objective was at least in principle attainable by requiring the control of water quality alone: "waters...shall be of sufficient quality to support..." It is also possible that high quality waters could flow through stream reaches which do meet the requisite biological condition, such as fully concrete channel facilities. In such a case, the "waters" cannot support a biological condition. This attempt to expand the definition of a water quality objective is also reflected in the Staff Report.[5]

The numeric objective also sets up an unreasonable standard—a single metric applicable to all wadeable streams in the San Diego Region. Both the BCG and the Developed Landscapes project developed as part of the State's Biointegrity Plan provide evidence that a range of CSCI scores are protective of good biological conditions and not all waterbodies will be able to attain reference

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[5] Draft Staff Report for proposed Biological Objectives for the San Diego Region, January 2018. Page 15; bottom of last paragraph: "...and the inability of chemistry-based assessment to detect impairment caused by pollution and not a pollutant (e.g. habitat modification)." This statement suggests that habitat modification meets the definition of "pollution;" however, this is not consistent with the definition of pollution in the Basin Plan: Pollution - Means an alteration of the quality of the waters of the state by wastes to a degree which unreasonably affects either of the following: (1) The waters for beneficial uses, or (2) Facilities which serve those beneficial uses. "Pollution" may include "contamination."

conditions. The proposed numeric objectives have no consideration for the actual range of conditions found in the region; including modified channels and lower watershed streams with sandy/silty bed materials. In addition, the proposed numeric objectives rely on an algal index as an additional line of evidence that has yet to be fully developed, vetted, or approved.

It is not reasonable to expect modified channels to entirely achieve the biological conditions defined by the narrative and numeric objectives:

1. There is no consideration for existing flood control infrastructure or modified channels;
    a. As written, all wadeable streams must achieve or eventually be restored to be equivalent to reference streams;

2. There is no consideration for areas managed for water conservation (diversions or spreading grounds);

3. Porter Cologne and the CWC recognize the need to balance societal needs and priorities to achieve the "highest water quality which is reasonable..." (When establishing water quality objectives). We need to determine what conditions are reasonably achievable. Recent science shows that reference conditions are unlikely to be achievable through rehabilitation efforts in watersheds with urbanization:

    a. Booth (2005);[6]" Long-term improvement of stream conditions is not feasible under typical urban constraints, so large sums of money should not be spent on unrealistic or unreachable targets for stream rehabilitation. However, such a strategy should not be an excuse to preclude potential future gains by taking irreversible present-day development or rehabilitative actions."

    b. Hughes et al, 2014[3]:
    "...urban water bodies cannot be restored to predisturbance conditions, but they can be improved to support desirable biota and water quality"

    c. Smith et al, 2016[2]:
    "Pervasive human impacts on urban streams make restoration to predisturbance conditions unlikely. The effectiveness of ecologically focused restoration approaches typically is limited in urban settings because of the use of a reference-condition approach, mismatches between the temporal and spatial scales of impacts and restoration activities, and lack of an integrative approach that incorporates ecological and societal objectives."

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[6] Booth, DB: Challenges and prospects for restoring urban streams: a perspective from the Pacific Northwest of North America. J. N. Am. Benthol. Soc., 2005, 24(3):724–737.

d. SMC, 2017[7]: "Although this opportunistic analysis of available SMC survey data suggests that an engineered channel may not be able to support aquatic life as well as natural streams can, and tradeoffs between flood protection and ecological condition may be unavoidable, it shows that a range of conditions is possible, and that better conditions may be possible through management of water quality and habitat."

e. State Water Board (Mazor, 2017)[1,8]; As discussed above, the Developed Landscapes Model identifies waterbodies where "developed land uses are likely to limit CSCI scores;"

It is not reasonable[9] to expect stream channels that have been modified to provide flood protection to achieve or maintain biological conditions that would meet the proposed Biological Objectives. Modified flood control systems do not provide a substrate capable of supporting a CSCI-compliant benthic invertebrate community, and do not provide vegetative cover or physical structural complexity that is similar to "unaltered analogous waters." Therefore, regardless of the actual quality of waters flowing through these systems, they will not achieve a reference-like biological condition. NPDES-regulated discharges from the municipal separate storm sewer system (MS4) do not cause or contribute to this condition. Therefore, there is no remedy to be obtained through regulation of MS4 discharges.

California Water Code 13241 Analysis

The Regional board must conduct an analysis under CWC Section 13241 as part of the water quality objective-setting process which include various factors designed to ensure "reasonable protection" of beneficial uses. CWC Section 13241 specifies:

> *"Each regional board shall establish such water quality objectives in water quality control plans as in its judgment will ensure the reasonable protection of beneficial uses and the prevention of nuisance; however, it is recognized that it may be possible for the quality of water to be changed to some degree without unreasonably affecting beneficial uses. Factors to be considered by a regional board in establishing water quality objectives shall include, but not necessarily be limited to, all of the following:*
>
> *(a) Past, present, and probable future beneficial uses of water.*

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[7] Stormwater Monitoring Coalition (SMC). 2017. Report on the Stormwater Monitoring Coalition's Regional Stream Survey. SCCWRP Technical Report 963. Southern California Coastal Water Research Project. Costa Mesa, CA. Available from: http://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/963_2015_SMC_Report_EnginChannels.pdf

[8] Sutula, M; Stein, E; Mazor, R; Theroux, S; Paul, M; Jessop, B; and Gerritsen, J: Draft Work Plan "Expert Interpretation Of The Biological Condition Gradient In California Wadeable Streams" November 2016 Update.

[9] CWC Section 13000: The Legislature further finds and declares that activities and factors which may affect the quality of the waters of the state shall be regulated to attain the highest water quality which is reasonable, considering all demands being made and to be made on those waters and the total values involved, beneficial and detrimental, economic and social, tangible and intangible.

(b) *Environmental characteristics of the hydrographic unit under consideration, including the quality of water available thereto.*

(c) *Water quality conditions that could reasonably be achieved through the coordinated control of all factors which affect water quality in the area.*

(d) *Economic considerations*

(e) *The need for developing housing within the region*

(f) *The need to develop and use recycled water.*

Proposed Implementation Actions

Proposed implementation actions to be required for the District as a permittee under the Regional MS4 Permit include biological monitoring of these modified conveyance systems, even where required maintenance will effectively limit the achievable biological condition[10]. In addition, the proposed implementation provisions suggest the need for causal assessments to determine the cause and potential remedy of biological objective impairments. For flood control conveyance systems, such assessments are unlikely to be of value since a primary cause of degraded biological condition is already known to be the conveyance system itself. In order to be considered reasonable, we believe any new adopted narrative or numeric biological objectives must allow for effective operation and management of flood control infrastructure.

The District acknowledges that the design and construction of flood control infrastructure must consider and minimize environmental impacts. In addition, there is a wide range of intensity of hardening among existing flood conveyance systems. Some conveyances have "soft" bottoms and minimal structural reinforcement and allow more opportunities for vegetation and habitat; while other systems require full concrete vertical wall channels to ensure safe conveyance of design floods through developed areas. In developed areas, private property typically constrains the width of existing flood control right-of-way, which is a primary limitation on channel design. All projects in southern California that build, reconfigure, or rehabilitate channels to a more natural condition will require 404 permits from the United States Army Corps of Engineers, 401 Certifications from the Regional Boards, and streambed alteration agreements from California Department of Fish and Wildlife; with requirements for mitigation in addition to the work on the channel itself. These factors constrain project opportunities and drive higher costs.

As stated in the Staff Report: Page 18, at 3.3.3: "The concept of 'analogous waters' is necessary in order to ensure that 'apples are being compared to apples' in the course of determining whether biological

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[10] Proposed Implementation Language, Page 5 of proposed Basin Plan Section 4: Monitoring and Assessment in Permitting: The Regional Board will include Biological Objectives monitoring and assessment requirements where Biological Objectives are incorporated as receiving water limitations into individually issued permit(s), Regional Phase I stormwater permits, and regional general permits, consistent with this chapter.

objectives are met." This concept should also apply to modified streams, so that unreasonable, and in some cases, unattainable, objectives are not applied inappropriately.

Comments from Other Agencies Supporting Objectives that Better Support Prioritization

The District also supports several comments which were made to the State Water Board related to the January 23, 2013 Workshop: Scientific Basis for Development of a Statewide Policy for Biological Objectives. Comments number 8, and numbers 10-14, from a joint letter prepared by CASA, Tri-TAC, SCAP, and the CVCWA[11] are relevant to the proposed Biological Objectives. Following are the summary statements from comments 8, 10, 12, and 13; detailed explanations can be found in the attached letter. Comments 11 and 14 are excerpted here in their entirety for clarity. We request that the San Diego Regional Water Board consider these as they apply to the proposed Biological Objectives in the San Diego Region.

Comment 8: We request that the variability of the CSCI associated with natural disturbances, particularly with inter-annual fluctuations in rainfall associated scouring events, be evaluated.

Comment 10: We recommend that the State Water Board pursue a Policy approach that utilizes the technical tools to prioritize streams instead of using it to make formal impairment decisions under the Clean Water Act.

Comment 11: In keeping with pursuing a prioritization approach, consideration should also be given to phasing implementation of the Policy. Under such a phased approach, the initial use of the Policy would be to incorporate monitoring and scoring with the new tools followed by establishment of priority classifications. Presumably, initial management priorities would be limited to the highest scoring streams in which reference conditions are attained. These streams potentially represent vulnerable and ecologically important areas and are the areas where existing causal assessment tools and corrective actions are most likely to be successful. In later phases, the Policy could be better developed using information learned from earlier phases including the effectiveness of management practices, reliability of achieving the desired biological condition, costs and other insights with the intent to eventually expand usage to other regions and areas. This will initially restrict use of the objectives and causal assessment tools to areas where there is little disagreement as to their applicability and where successful causal identifications are most likely to be obtained. Subsequent phases to extend applicability where appropriate can then be considered and developed utilizing the lessons learned and new tools developed during the previous phases as more information on the appropriateness of applying biological objectives to these areas is obtained.

Comment 12: Therefore, the State Water Board should carefully evaluate the efficacy of setting biological objectives that may result in the need to alter or to reduce capacity of modified channels

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[11] Comment Letter – Board Workshop: Scientific Basis for Development of a Statewide Policy for Biological Objectives. Submitted jointly by the California Association of Sanitation Agencies (CASA), Tri-TAC, the Southern California Alliance of Publicly Owned Treatment Works (SCAP) and the Central Valley Clean Water Association (CVCWA); dated February 25, 2013.

providing vital and necessary public services such as flood control, water supply, agricultural drainage, and other critical services.

Comment 13: Therefore, the State Water Board should carefully evaluate the efficacy of setting biological objectives that may result in restricting recycled water projects, expansion of existing recycled water programs, and the ability to utilize channels and streams for delivery of recycled water.

Comment 14: State Water Board staff recognize that reference biological expectations for some perennial and wadeable streams are not reasonable and have proposed alternatives that would establish an intermediate biological threshold lower than that of reference condition ("best attainable") for these streams. This approach functionally "tiers" the biological expectation to some lower level even though the designated aquatic life beneficial use for the stream may remain the same as those in a more pristine or reference state. We believe that a more systematic approach that would ensure that beneficial uses and water quality objectives are appropriately matched is to create additional subcategories of the aquatic life use and apply them as appropriate within each region, similar to an approach that has been successfully incorporated into Ohio's regulatory program that uses "tiered aquatic life uses" (TALU). In Ohio, the biological expectation has been adjusted up or down based on what is minimally necessary to support the tiered beneficial aquatic life use, recognizing that not all streams and channels should be expected to support the same beneficial use. Another approach would be to include a subcategory such as "Limited Warm Freshwater Habitat," defined by the Santa Ana Regional Water Quality Control Board to be waters "which support warmwater ecosystems which are severely limited in diversity and abundance as the result of concrete-lined watercourses and low, shallow dry weather flows which result in extreme temperature, pH, and/or dissolved oxygen conditions. Naturally reproducing finfish populations are not expected to occur in Limited Warm Freshwater Habitat Waters." (Santa Ana Region Basin Plan, Chapter 3, p. 4) State Water Board staff are proposing to tier/reduce the biological expectation knowing that meeting such an expectation will still not support the highest level of the desired beneficial use (or meet the narrative biological objective) because the beneficial use will remain unchanged. Therefore, the "best attainable" threshold becomes an arbitrary target that will not result in attainment of the biological objective and may or may not be necessary to support the desired aquatic life beneficial use. For these reasons, it is imperative that the State Water Board evaluate an alternative that includes modifying both beneficial uses and water quality objectives to match those uses.

Constraints on Attainable Biological Conditions in the Santa Margarita Watershed

The concept of prioritizing waterbodies and developing tiers that can be used to determine the "best attainable" thresholds for waterbodies will support prioritization of actions and protection of high quality waters. Without consideration of the best attainable condition, waterbodies that are high scoring as compared to expectations, but below the numeric objectives, would likely be prioritized for implementation actions. However, these implementation actions would likely not result in a meaningful change in the CSCI score. On the other hand, waterbodies that should and could score higher but are meeting objectives or ambiguous would be a lower priority even though implementation actions would be more likely to provide meaningful improvement in these waters. The following two figures demonstrate how using the Developed Landscapes Tool to set tiered expectations for different waterbodies provides support for prioritization that is missing when the waterbody expectations are not considered. The plots show SMC monitoring sites in the Santa Margarita River Watershed (many of which are shown in Figure 1 for the Upper Santa Margarita River Watershed). Figure 2 shows the SMC monitoring data without information regarding the constraints and predicted CSCI scores for the waterbody and Figure 3 shows the same data with the predicted range of CSCI scores. The black line is the proposed 10th percentile numeric objective of 0.79. Without the context of the constraints and predicted CSCI scores, actions could be prioritized for waterbodies on the bottom of the graphic that fall on likely or potentially constrained waterbodies because they fall well below the proposed numeric objective. However, the sites in blue that are below the objective are more likely to be able to be restored and meet the objective and would therefore be better to prioritize even though the CSCI scores are higher.

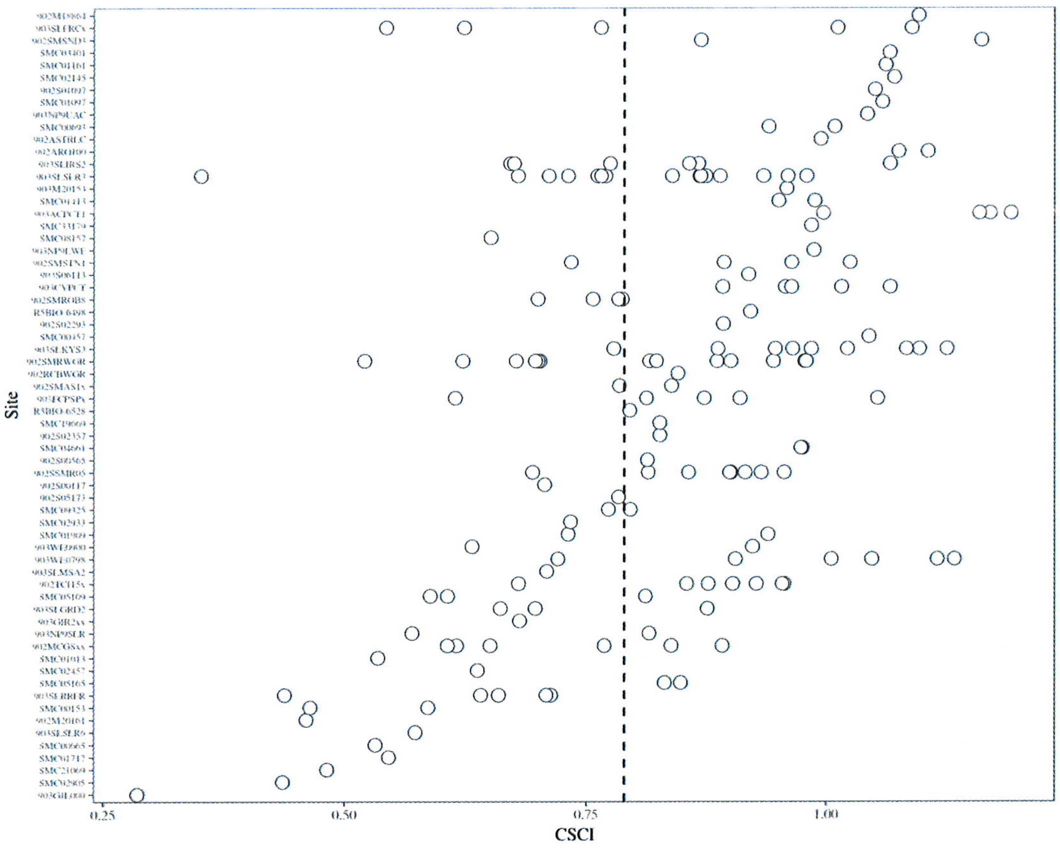

Figure 2. Santa Margarita River Watershed SMC Bioassessment Monitoring Results Presented Without Context of Waterbody Constraints

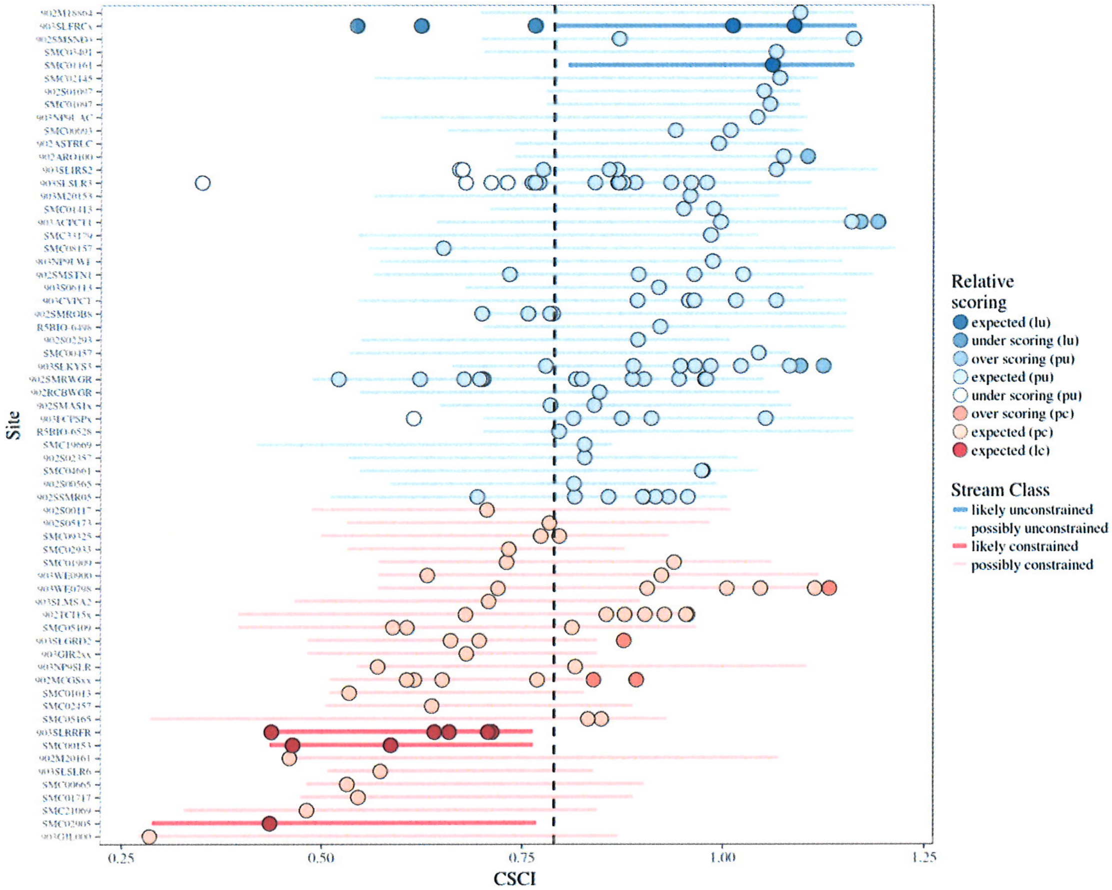

Figure 3. Santa Margarita River Watershed SMC Monitoring Sites with Waterbody Expectations [12]

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[12] Plots generated from https://beckmw.shinyapps.io/biological_constraints/. Website created by SCCWRP.

Recommendations
Conduct the required analysis under CWC Section 13241 as part of the water quality objective-setting process. In addition to the specified factors, the Regional Board should specifically evaluate the cost, feasibility, and societal implications of restoring the urbanized watershed areas and the existing flood control infrastructure to the requisite conditions specified by the proposed Biological Objectives.

Revise the narrative objective to read similar to the description proposed at the CEQA Scoping Workshop in July 2016, such that, it is reasonable and achievable. The narrative objective should clearly apply to water quality (e.g., narrative objective text should read: "...waters...shall be of sufficient quality..."), and should allow for non-reference conditions where appropriate. Reasonable objectives would support a prioritization approach that weighs all factors and that focuses resources where they will achieve the most benefit. All stream reaches in the region would be considered, however, watershed issues would be addressed in order of priority. Even the challenge of improving CSCI scores in hardened flood control channels would be evaluated and prioritized according to all relevant factors.

Replace the numeric objectives with numeric guidance that reasonably addresses the range of existing and probable future channel conditions in the region, including modified flood control facilities and water conservation or water recycling projects. Use the science and information from the State's Biointegrity Plan, in coordination with scientists from SCCWRP, to develop the numeric guidance. The guidance would use the results of the BCG project to assign a range of best attainable CSCI scores to the waterbody categories defined by the Developed Landscapes project (e.g. likely constrained, likely high quality). As part of developing the numeric guidance, the variability of the CSCI in response to natural disturbances such as rainfall fluctuation should be considered. Additionally, the District requests that the Regional Water Board staff evaluate the use of tiered aquatic life uses, which includes modifying beneficial uses and developing water quality objectives appropriate to protect those uses.

The implementation section should also be revised to reflect the tiered numeric guidance to support a focus on protecting high quality waters and prioritization of implementation efforts on waterbodies where restoration is likely to improve the biological condition. Suggested modifications include:

- Use bioassessments to prioritize streams for watershed management activities, not to make formal impairment decisions and place existing permitted flood control facilities on the 303(d) list;
- Phase the implementation of the proposed Biological Objectives, starting with identifying and taking steps to protect the streams in best condition and building tools and experience to apply to progressively more impacted streams.

- Link required implementation actions clearly to the numeric guidance. For example, streams that are identified as "likely high quality" would be given a higher priority for further evaluation and implementation actions than streams identified as "likely constrained" and expected to fall below the range of expected CSCI scores for the waterbody category. Waterbodies within or above the predicted range of CSCI scores for the waterbody category would be considered meeting objectives even if the scores were not at reference levels.

- Do not require monitoring of all existing flood control facilities; rather use monitoring to further characterize high priority and unknown areas and to assess streams over time; and

- Do not require causal assessments where the main cause is channel modification or in intensely urbanized areas.

If you have questions or need additional information please contact Matt Yeager at 951.955.0843 myeager@rivco.org or me at 951.955.1273 eequinon@rivco.org.

Very truly yours,

EDWIN QUINONEZ
Chief of Watershed Protection Division

ec: Richard Boon
Rebekah Guill
Matt Yager
Santa Margarita MS4 Permittees

Attachments:
- Mazor, 2017
- SMC, 2017
- Smith et al., 2016
- Hughes et al., 2014
- Sutula et al, 2016
- Booth, 2005
- February 25, 2013 Comment Letter to State Board

Constraints on biological integrity in streams in developed landscapes

Presentation to Science Panel

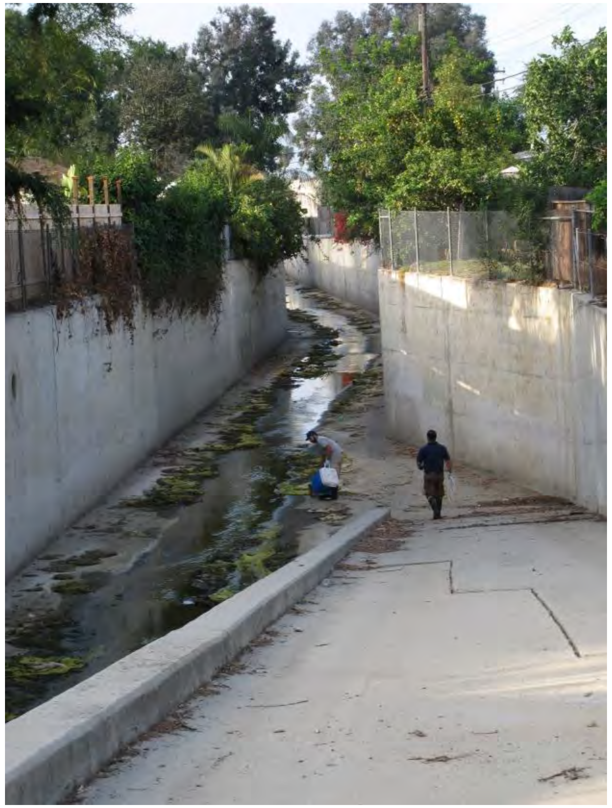
April 19, 2017

Raphael Mazor
raphaelm@sccwrp.org

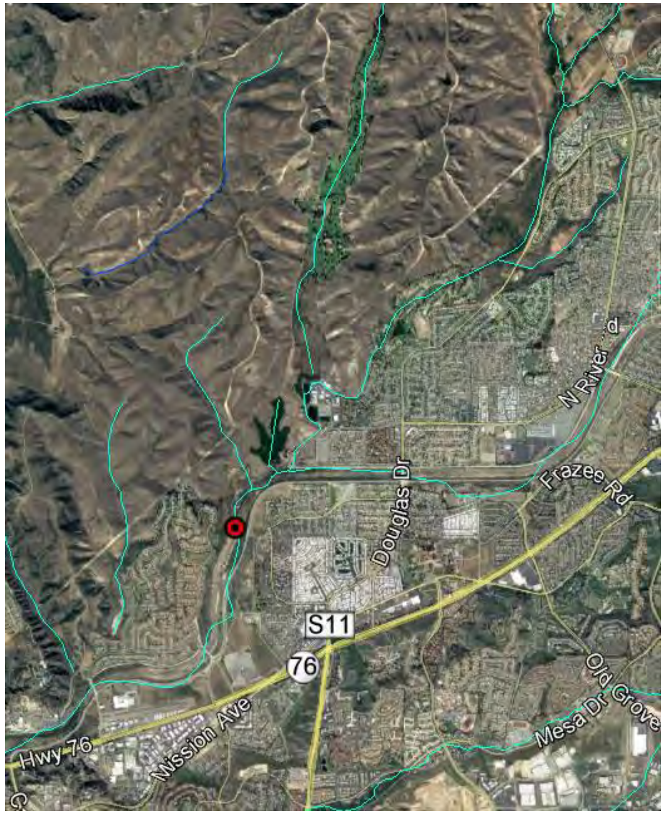
Policy context and goals

- The Water Boards are committed to exploring options for managing streams with constrained biological integrity
    - E.g., different priorities or timeframes for improvements
    - “Alternative thresholds unlikely”
- Management options will be discussed during policy development, but may not be set within this policy.
- We will develop one way of screening streams that may be constrained by landscape development.
    - Statewide screening based on GIS
    - Field visits and other data may also play a role
    - Screening is a starting point, not the final word.

Two ways to identify constrained streams: Channels vs Landscapes



Modified channel

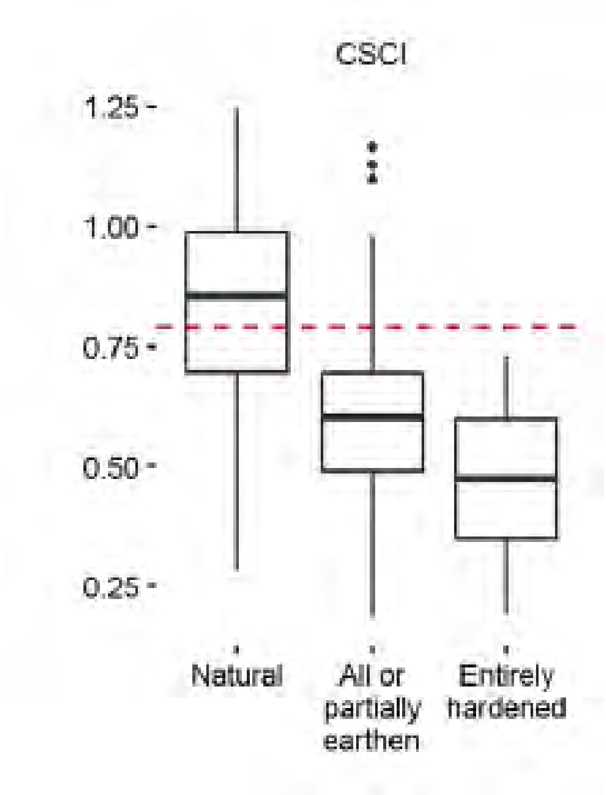


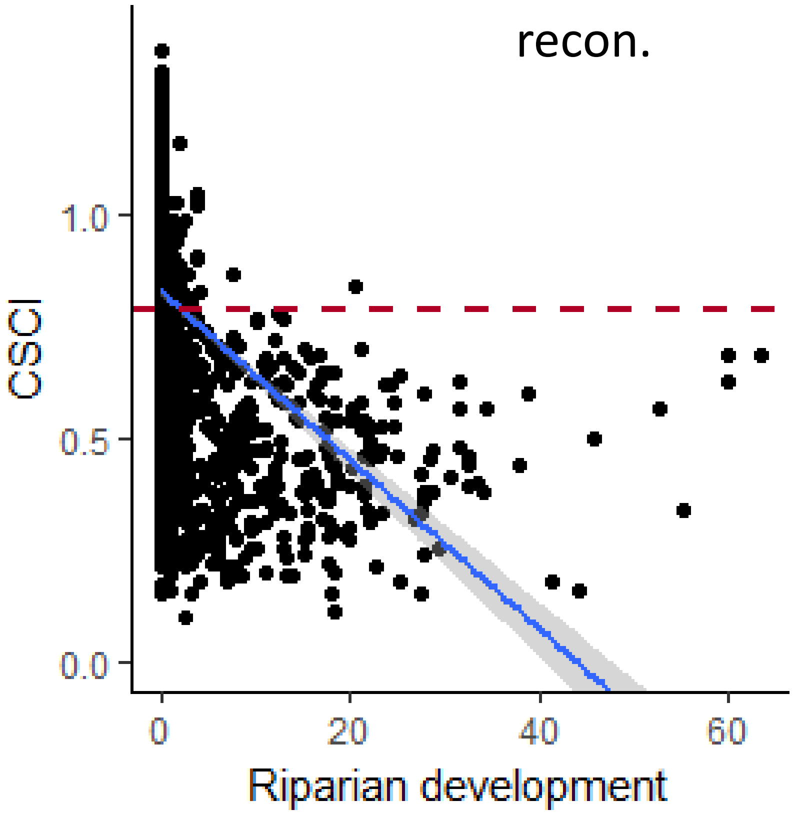
Developed landscape

- Field determination vs. GIS
- Harder to map channel mod
- Channel mod may define the problem too narrowly
- Both approaches have strengths, but landscape approach is better for screening and statewide application

Development can constrain biological integrity

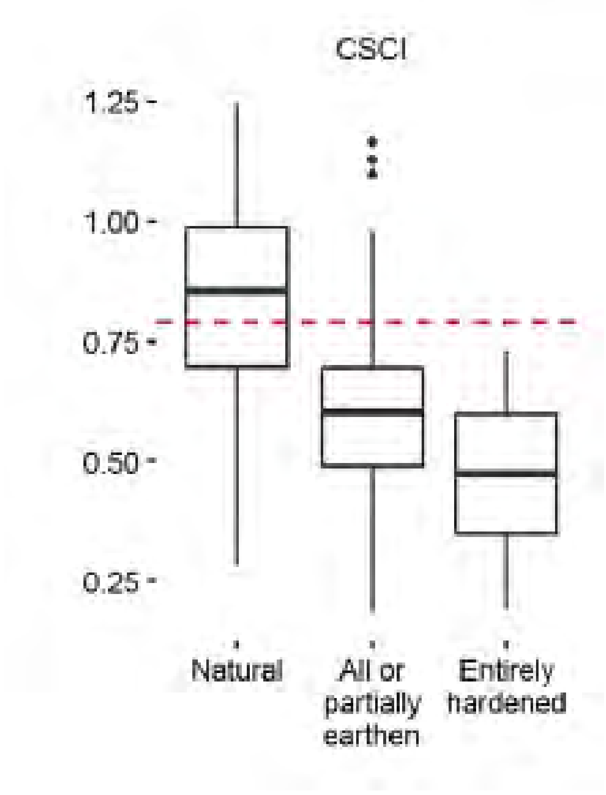
- Pilot study on ~500 sites in SoCal region.
- Channel status determined in field visits or desktop recon.

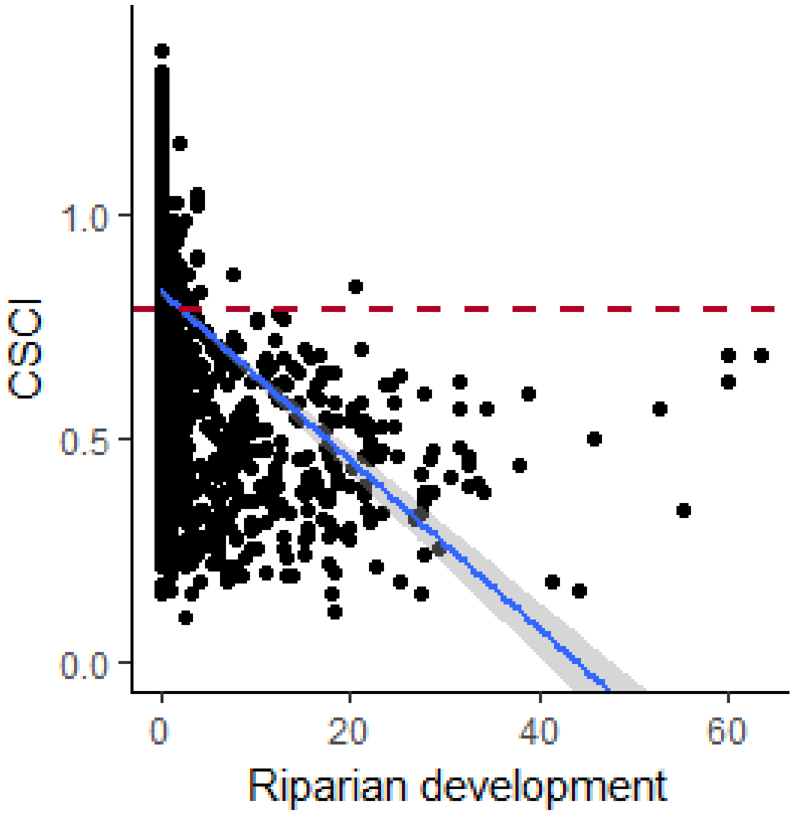


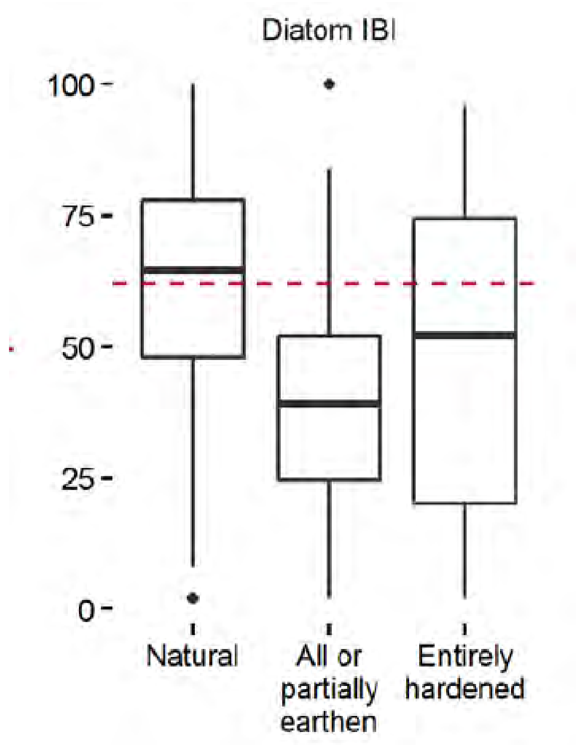


High scores (above threshold) rarely, if ever, seen in certain stream types

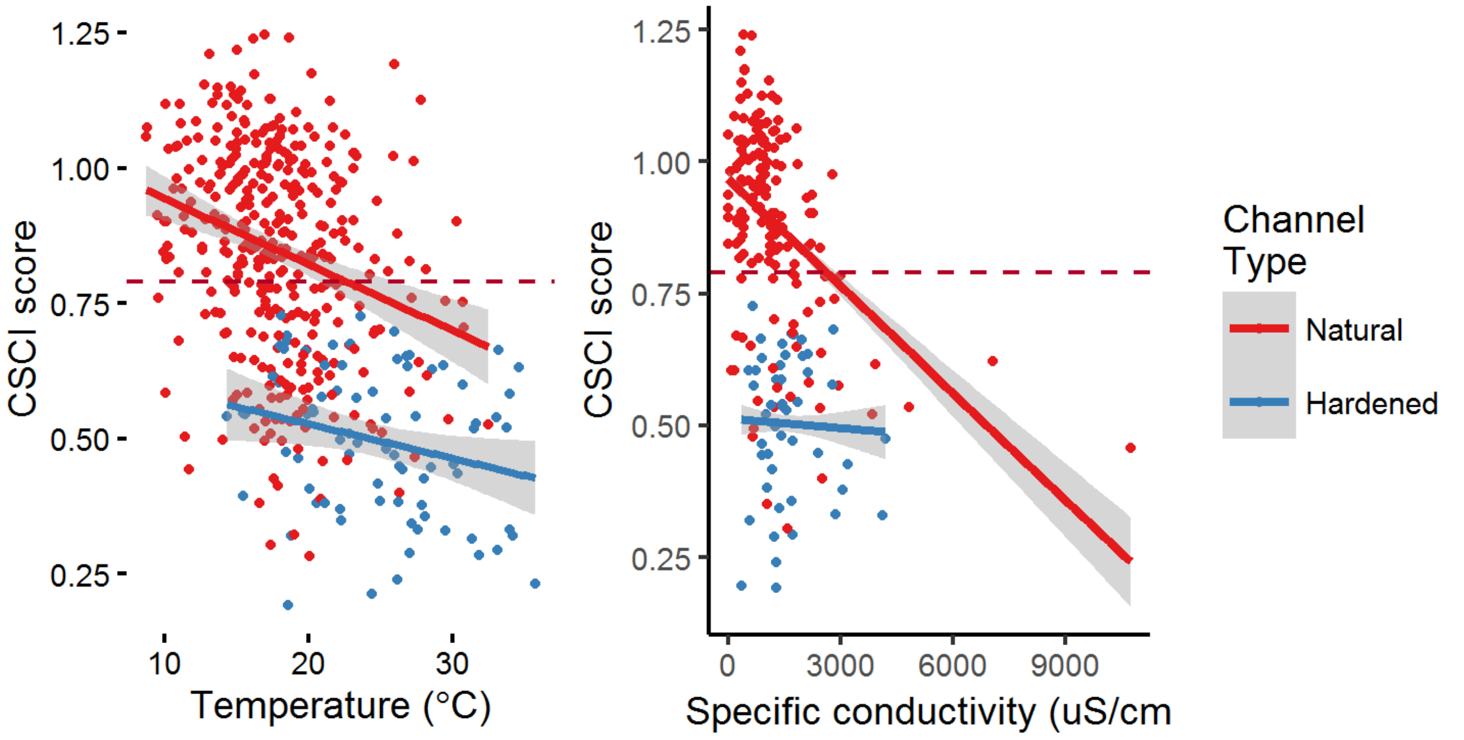
Development can constrain biological integrity (bugs more so than algae)





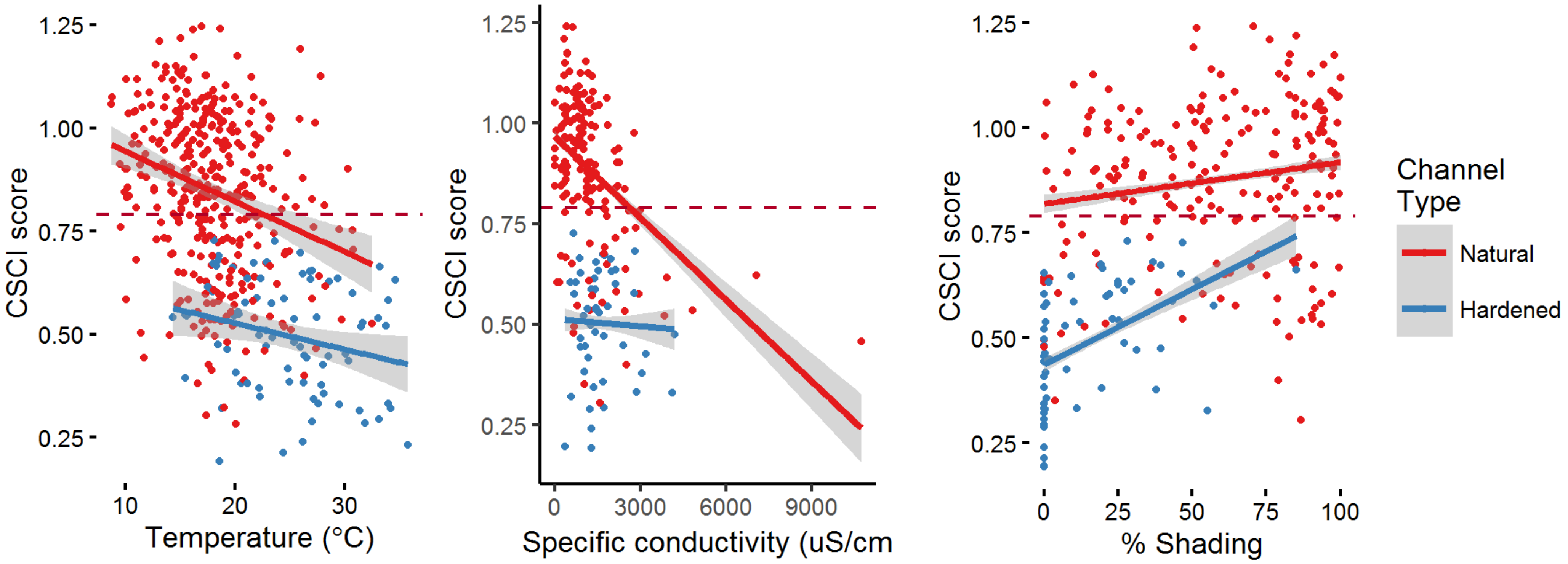


Dampened response to WQ gradients



Improving WQ may not protect bio-integrity

Dampened response to WQ gradients



(although some factors show a strong influence)

Tentative definition of developed landscapes

Landscapes where developed land uses are likely to limit CSCI scores

(…and ASCI scores)

Approach

- Build a model to predict ranges of CSCI scores associated with land use gradients
  - Select land use parameters (e.g., urban or ag land cover)
  - Use national STREAMCAT database of watershed characteristics: Easy statewide applicability
  - Quantile random forest: Provides *range* of likely CSCI scores in different landscapes
- Identify landscapes where statewide “default” assessment endpoints are *unlikely* to be met

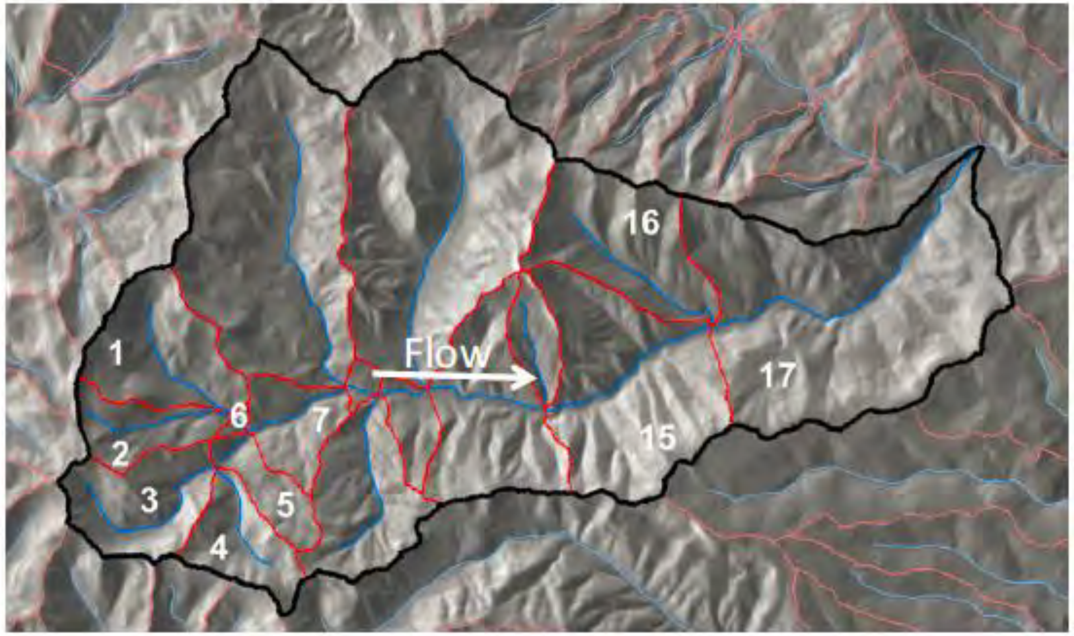
Three key factors in modeling decisions

1. Model development: What kinds of variables should we include?
2. Model application: What thresholds to use for identifying likely “high” or “low” scoring streams?
3. Model application: What likelihoods for defining “likely” or “unlikely”?

- Tech team is evaluating these decisions with Regulatory Advisory Group on an iterative basis

Predictor data source: STREAMCAT

- Nearly all stream segments from NHD+ (1:100k scale) represented
- Lots of data calculated for each watershed and catchment
  - Metrics also calculated for 100-m riparian buffers
- STREAMCAT makes it easy to explore statewide landscape models on a large scale



Types of data in STREAMCAT

- Natural variables (e.g., geology, climate, watershed area)
  - These DON’T affect CSCI scores! No need to include in models.
- Stressor variables
  - These DO affect CSCI scores
  - Some reflect transient impacts (e.g., pesticide)
  - Some reflect long-term impacts (e.g., landcover)
  - Some are debatable, especially in rural settings (e.g., roads, dams, imperviousness, mines)
- Different variables are good for different models and applications
  - Is it appropriate to include transient stressors in modeling landscape constraints?
- Tech team has preliminary classifications, currently being vetted with Regulatory Advisory Group

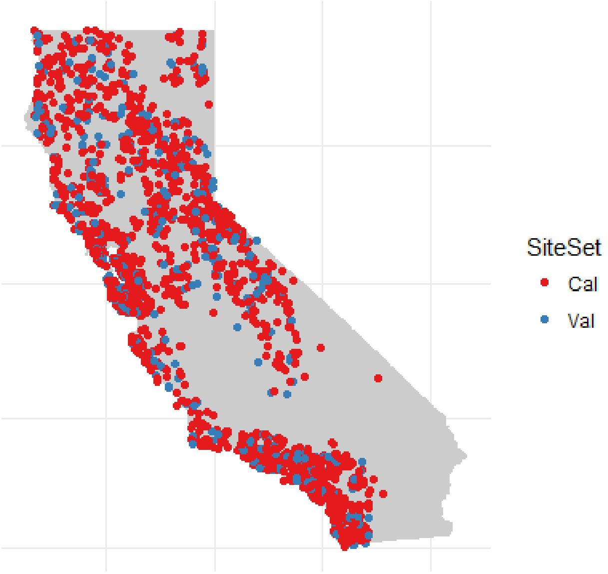
Channelization/Armoring

- Poorly characterized in STREAMCAT, other GIS sources
- Statewide, NHD-registered data not available

But is this a problem?

- Many armored streams are captured by other variables (e.g., riparian landcover)
- May be better addressed after landscape-scale screening with field data (e.g., physical habitat data)

Building the models



Preliminary work:

- 3252 sites, split 80% calibration 20% validation
  - Stratified by 6 PSA regions
  - Each region further stratified into quartiles by watershed imperviousness
- Where multiple samples are available, only one randomly selected for modeling

Impervious quartiles

Region	Q1	Q2	Q3
North Coast	0.02	0.07	0.15
Chaparral	0.09	0.28	3.35
South Coast	0.16	1.15	10.30
Central Valley	0.35	1.11	10.15
Desert-Modoc	0.06	0.13	0.21
Sierra Nevada	0.04	0.15	0.29

Based on RG and SG feedback….

“Core” candidate predictors:

- NHD+ Canal density
- NLCD land-cover (aggregated to urban and ag)
- Density of roads and road crossings

Additional/alternative candidate predictors we may explore:

- NLCD (urban and ag, not aggregated)
- Mine density
- Dam storage
- Atmospheric deposition (Nitrogen, Sulfur)

Model training

- Recursive feature elimination in caret package in R
- Evaluate all possible models with 5 to 15 candidate predictors
- Pick the "best" (lowest RMSE) model for each model size, and the overall best
- Pick the simplest model with RMSE within 1% of the overall best.

Example

Variables	RMSE	% of best	Selected
5	0.1769	2.1	
6	0.1763	1.8	
7	0.1751	1.1	
8	0.1756	1.4	
9	0.1745	0.8	Selected
10	0.1740	0.5	
11	0.1732	0	Best
12	0.1737	0.3	
13	0.1740	0.5	
14	0.1740	0.5	
15	0.1741	0.5	

So far, investigations show:

- Not a big difference among models (all pseudo-R^2 between 0.54 and 0.58)
- Variables that occur in rural areas (e.g., low-density urban, ag, road density, atmospheric deposition) are more influential than variables that are restricted to heavily developed areas (e.g., high-density urban)

Variable	Core	Core-Plus
Land use		
PctImp2006Cat	Sel	Sel
PctImp2006Ws	Rej	Rej
PctImp2006CatRp100	Rej	Rej
PctImp2006WsRp100	Sel	Rej
TotUrb2011Ws	Sel	Rej
TotUrb2011Cat	Rej	Rej
TotUrb2011WsRp100	Sel	Rej
TotUrb2011CatRp100	Rej	Rej
TotAg2011Ws	Sel	Sel
TotAg2011Cat	Rej	Rej
TotAg2011WsRp100	Sel	Sel
TotAg2011CatRp100	Rej	Rej
Non-native veg cover		
PctNonAgIntrodManagVegCat	NC	Sel
PctNonAgIntrodManagVegWs	NC	Sel
PctNonAgIntrodManagVegCatRp100	NC	Sel
PctNonAgIntrodManagVegWsRp100	NC	Sel
Mines		
MineDensCat	NC	Rej
MineDensWs	NC	Rej
MineDensCatRp100	NC	Rej
MineDensWsRp100	NC	Rej

Variable	Core	Core-Plus
Roads		
RdDensCat	Rej	Rej
RdDensWs	Sel	Sel
RdDensCatRp100	Rej	Rej
RdDensWsRp100	Rej	Rej
RdCrsCat	Rej	Rej
RdCrsSlpWtdCat	Rej	Rej
RdCrsWs	Sel	Rej
RdCrsSlpWtdWs	Sel	Sel
Atmospheric deposition		
NH4_2008Ws	NC	Sel
NO3_2008Ws	NC	Sel
InorgNWetDep_2008Ws	NC	Sel
SN_2008Ws	NC	Sel
Hydrology		
CanalDensCat	Rej	Rej
CanalDensWs	Sel	Rej
DamDensCat	NC	Rej
DamDensWs	NC	Rej
DamNrmStorM3Cat	NC	Rej
DamNrmStorM3Ws	NC	Rej

Rejected

Selected

Not considered

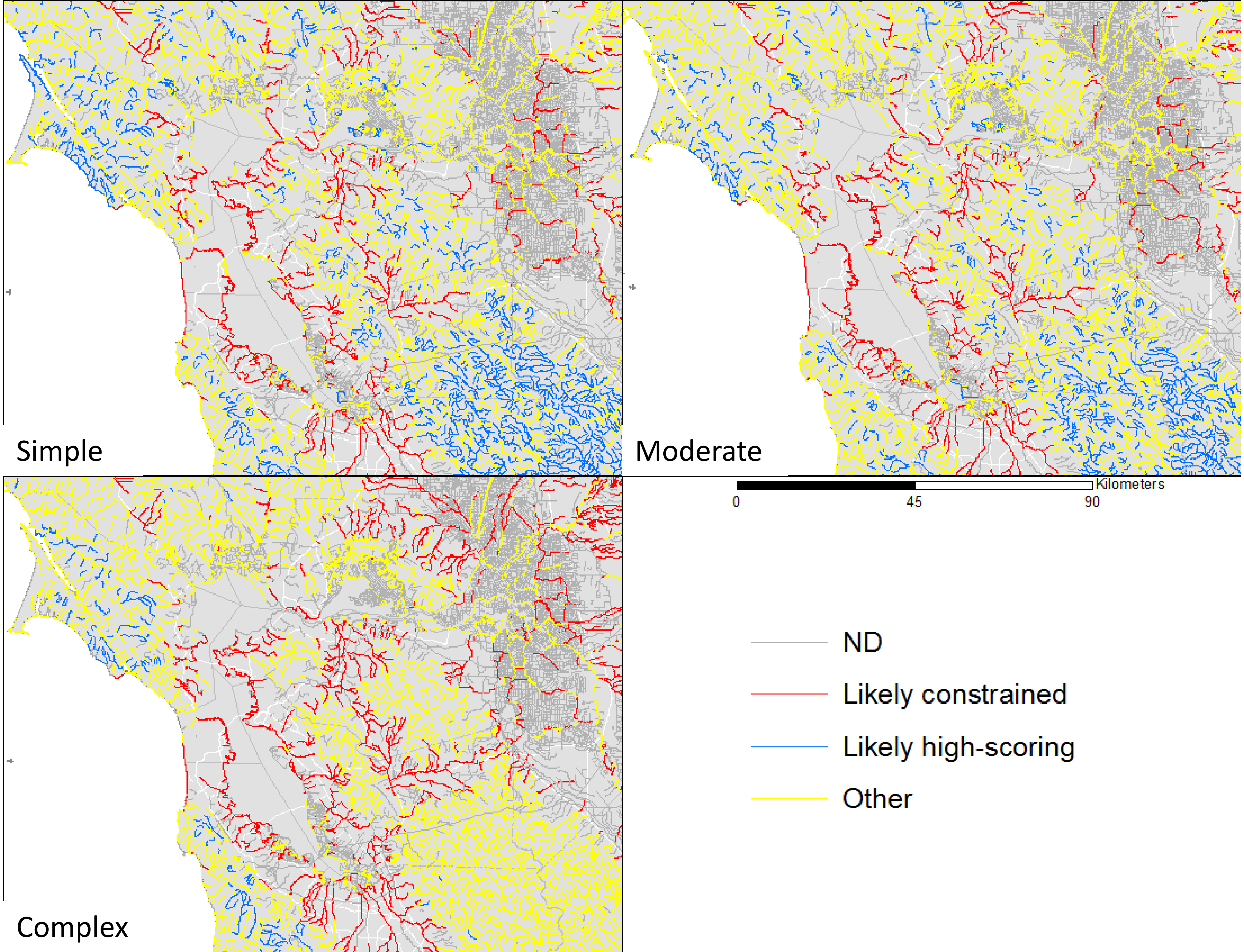
What are the outcomes of these models?

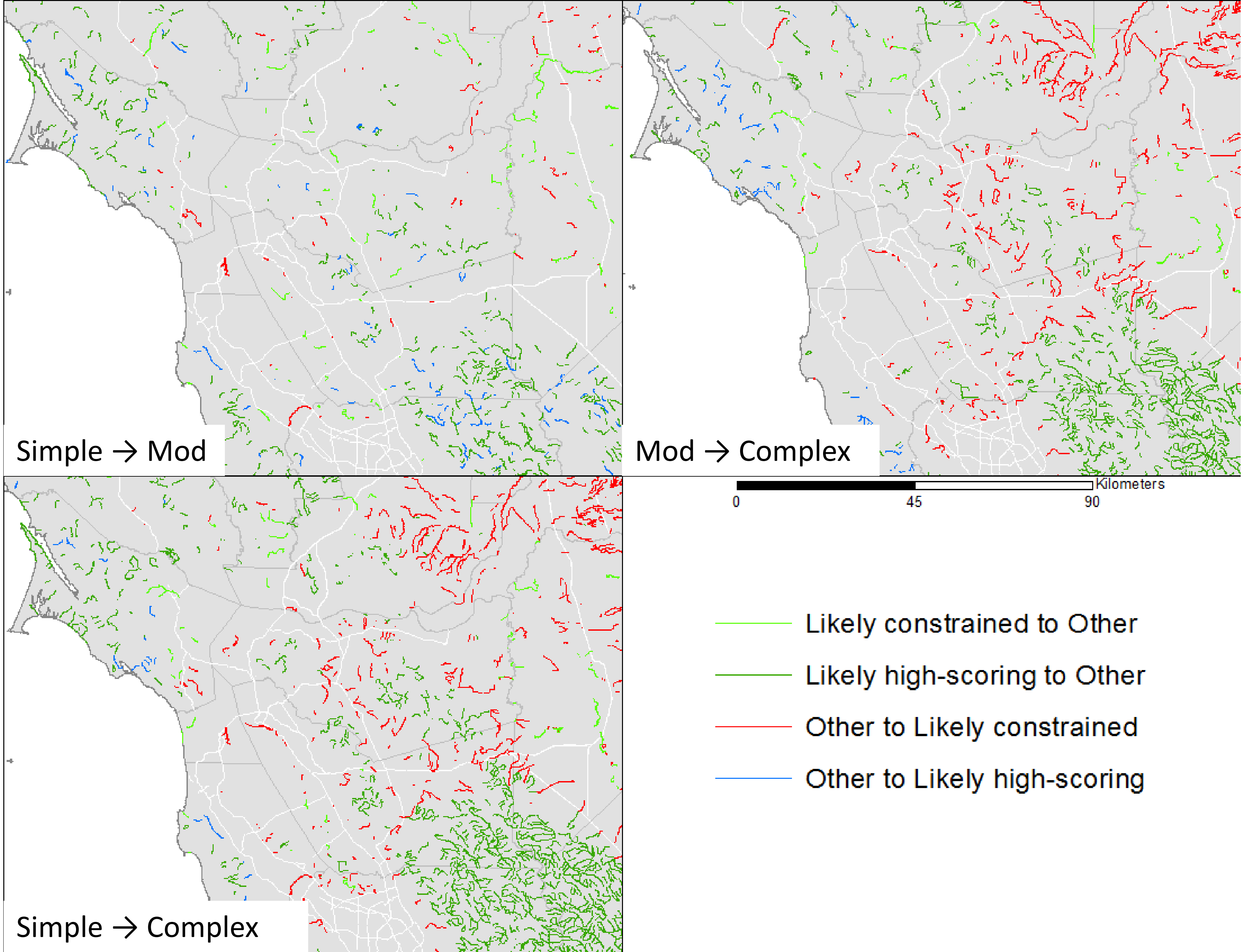
- Outcomes allow classification and identification of stream types:
  - Likely constrained: <10% chance of scores over decision point (e.g., 0.79)
  - Likely high-scoring: <10% chance of scores under decision point
- Alternatively, you could tweak model parameters to simulate optimal management
  - E.g., assume effective imperviousness can be reduced 50%
  - May not be realistic
- While more complex models identify the greatest number of constrained streams/lowest number of high-scoring streams, this can be changed with different classification schemes.

We want a classification scheme that reflects our assumptions/values, not one that produces the map we like best

Example maps (from previous analyses)

- Maps showing classifications for the Bay Area for 3 different types of models
  1. Likely low-scoring / constrained
  2. Likely high-scoring
  3. Other
  4. Not determined
- Maps showing disagreements among models in the Bay Area
  - Simpler model vs more complex model
    1. Likely constrained to other
    2. Likely high scoring to other
    3. Other to likely constrained
    4. Other to likely high scoring


Simple
Moderate
Complex
0
45
90
Kilometers
ND
Likely constrained
Likely high-scoring
Other


Simple → Mod
Mod → Complex
Simple → Complex
0
45
90
Kilometers
Likely constrained to Other
Likely high-scoring to Other
Other to Likely constrained
Other to Likely high-scoring

There are many potential applications of these models

Highlighted in Belluci et al. (2013) models of Connecticut streams, and in discussions with advisory groups:

- Lines of evidence in 305b/303d assessments
- Identifying high-quality streams
- Targeting of “underperforming” sites for follow-up monitoring
- Benchmarks for anti-degradation where only 1 sample is available

Water board will explore these options with advisory groups

Next steps

- Refine and validate models (now through May)
  - Incorporate feedback from advisory groups
  - Simplify and test models with validation data
  - Repeat with ASCI (Late Summer)
- Produce and distribute maps/data (May)
  - Create interactive interfaces to explore products and impact of design decisions
- Discuss outcomes with advisory groups (Summer)
- Produce report (Late Summer/Fall)

Questions for panel

- Is this a valid approach to screening streams where bio-integrity may be constrained?
- What factors affecting stream condition are these models likely to miss?
- Any pitfalls we should watch for?

Types of variables we may include in models

Simple	Moderate	Complex
Urban land cover (NLCD 2011) Ag land cover (NLCD 2011) Canal density (NHD+)	All CDLmin variables Mine density Dam density and storage Road density Road crossings	All CDL and CDLmin variables Impervious surfaces (NLCD 2006) Fertilizer applications Pesticide applications (1997) Non-native veg cover Forest loss Fire perimeters Aerial deposition of N, S
Just a few “permanent” stressors. Best for identifying constraints?	Includes some “debatable” stressors.	Includes “transient” stressors. Best for predicting CSCI scores?

Urban stream renovation: incorporating societal objectives to achieve ecological improvements

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Abstract: Pervasive human impacts on urban streams make restoration to predisturbance conditions unlikely. The effectiveness of ecologically focused restoration approaches typically is limited in urban settings because of the use of a reference-condition approach, mismatches between the temporal and spatial scales of impacts and restoration activities, and lack of an integrative approach that incorporates ecological and societal objectives. Developers of new frameworks are recognizing the opportunities for and benefits from incorporating societal outcomes into urban stream restoration projects. Social, economic, cultural, or other benefits to local communities are often opportunistic or arise indirectly from actions intended to achieve ecological outcomes. We propose urban stream renovation as a flexible stream improvement framework in which short-term ecological and societal outcomes are leveraged to achieve long-term ecological objectives. The framework is designed to provide additional opportunities for beneficial outcomes that are often unattainable from ecologically focused restoration approaches. Urban stream renovation uses an iterative process whereby short-term ecological and societal outcomes generate public support for future actions, which may provide opportunities to address catchment-level causes of impairment that often exist across broad temporal scales. Adaptive management, education, and outreach are needed to maintain long-term public engagement. Thus, future work should focus on understanding how ecological and societal contexts interact, how to assess societal outcomes to maintain stewardship, developing new methods for effective education and outreach, and multidisciplinary collaborations. We discuss potential abuses and the importance of linking societal outcomes to long-term ecological objectives.

Key words: stream restoration, urbanization, ecological, societal, adaptive management, stewardship, environmental education

As the global human population continues to grow, the need for strategies to mitigate anthropogenic impacts on stream ecosystems continues to increase. Researchers in applied stream ecology have responded by developing refined bioassessment protocols (e.g., Wright 2000, Bonada et al. 2006), land development strategies that minimize negative effects on stream environments (Dietz 2007, Ahiablame et al. 2012), and new or improved approaches to stream restoration (Fletcher et al. 2014, Roy et al. 2014). Stream restoration approaches have shifted from hard-engineered

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solutions focused on ecosystem structure to the use of natural channel forms and processes to support ecosystem structure and function (Niezgoda and Johnson 2005, Palmer and Febria 2012, Naiman 2013, Hale et al. 2015).

From an ecological perspective, consistently effective strategies for restoring streams in urban catchments are elusive (Sudduth et al. 2011, Violin et al. 2011, Laub et al. 2012). The primary ecological barriers for restoring streams in modified landscapes is the extent to which drivers of stream condition (e.g., flow, sediment supply, water quality, habitat availability, etc.) and patterns of dispersal are modified by human activities (Bond and Lake 2003, Palmer et al. 1997, Smith et al. 2009). Frameworks like the urban stream syndrome (USS; Walsh et al. 2005) or that proposed by Wenger et al. (2009), which summarize the processes by which humans alter stream ecosystems, can help identify stressors and guide restoration efforts. The effect of specific stressors can sometimes be quantified to inform project design (Craig et al. 2008, Vietz et al. 2014), but characterizing the relationships among all drivers of environmental degradation to inform stream restoration projects is challenging.

At the 3rd Symposium on Urbanization and Stream Ecology (SUSE3), a working group of scientists from 7 countries, including students and professionals from academia, government agencies, and private industry, sought to develop a framework that could increase opportunities for achieving beneficial outcomes from efforts to improve urban streams. Our primary objective was to develop a flexible alternative to ecologically focused restoration that would provide options for short- and long-term improvements to urban streams that may be pervasively impaired by human actions. As part of this primary objective, we intended to challenge the philosophy that restoration projects are futile unless they are able to address all the 'causes' of the urban stream syndrome (e.g., excess stormwater runoff; Moran 2007, Roy et al. 2008, Walsh et al. 2012, Fletcher et al. 2014). In so doing, we discussed the merits of a framework based on an integrated approach that considers both 'ecological' and 'societal' (Table 1) perspectives for achieving long-term improvements in ecosystem structure and function.

Our goal in this synthesis paper is to discuss the resulting conceptual framework developed from that working group. We briefly describe the ecological and societal characteristics of urban streams and discuss the deficiencies of traditional (ecologically focused) restoration approaches in urban settings. We introduce the concept of urban stream renovation as a complementary alternative to stream restoration in urban landscapes that leverages an integrative approach to accomplish long-term ecological improvements. We discuss: 1) the integration of societal outcomes, 2) the role of adaptive management, 3) ways to implement the framework, and 4) research needs and potential future directions required to develop this framework further. We think the product is a fresh take on improving urban streams based on a novel approach that addresses many shortcomings of restorations in urban settings.

Table 1. List of terms used to describe the urban stream renovation framework and how they are used in this manuscript (see also Fig. 2).

Term	Definition as used in this manuscript
Ecological	Biological, geophysical, and chemical structures (e.g., biodiversity, channel forms, etc.) and functions (e.g., nutrient cycling, discharge, etc.) of stream ecosystems.
Societal	Social, cultural, political, economic, and historical properties of stream ecosystems.
Action	Physical manipulation of the channel, riparian zone, floodplain, or catchment. Actions generate outcomes, which originate from project objectives. Outcomes can result directly and indirectly from actions.
Short-term outcome	Short-term ecological and societal responses by the stream or human population (e.g., local community) to the action(s) performed (societal outcomes lead to future actions supporting incremental steps towards long-term ecological outcomes).
Long-term outcome	Steady or dynamic ecological or societal state of the stream (long-term outcomes result from the cumulative short-term outcomes guided by adaptive management).
Objective	A general descriptor of the desired short- or long-term results of the individual actions (an objective's success is determined by the short- and long-term outcomes achieved as a result of project actions).

ECOLOGICAL AND SOCIETAL CHARACTERISTICS OF URBAN STREAMS

In this paper, we use 'ecological' to mean the biological, geophysical, and chemical structures (e.g., biodiversity, channel forms) and functions (e.g., nutrient cycling, discharge) of stream ecosystems and 'societal' to mean the social, cultural, political, economic, and historical properties of stream ecosystems (Table 1). Demographic and economic (societal) factors drive urban development, and urban land cover alters the biotic and abiotic (ecological) conditions of urban stream and riparian ecosystems (Findlay and Taylor 2006, Hong et al. 2009). The societal drivers of landuse development are rarely included in studies examining urban impacts on biological integrity. Integrative studies of stream condition may be limited by the differences in spatial and temporal scales of societal (city, state, etc.) and ecological (watershed, riparian, etc.) drivers (Hong et al. 2009), difficulties in taking a multidisciplinary approach, or other logistical or conceptual barriers. Regardless of these difficulties, the substantial influence of societal contexts for stream improvement projects in densely populated urban areas suggests that an integrative approach to improving streams would be beneficial (Eden and Tunstall 2006).

A wealth of research shows that human effects in urban landscapes are diverse, interactive, confounded, and often pervasive. The hydrologic, chemical, physical, and biological attributes of aquatic ecosystems are severely and, sometimes irreversibly, altered in urban settings (Paul and Meyer 2001, Walsh et al. 2005, Wenger et al. 2009). Nevertheless, as seen during the SUSE3 conference and presented in other articles in this special issue (Cook and Hoellein 2016, Walsh and Webb 2016), an understanding of the mechanistic links among stressors and biotic and abiotic responses of stream ecosystems is evolving.

The relationship of urban streams with human populations is developed through a social process in which human experiences and the perceived characteristics of a location form a sense of attachment, belonging, or affinity for a particular geographic location, such as an urban stream (this framework is often referred to as 'sense of place'; Williams and Stewart 1998). That is, human perceptions of urban streams are derived from subjective valuations of aesthetic properties, ecological condition, historical significance, perceived threats to personal property, and functionality for commerce, transportation, recreation, among other factors (Ryan 1998, Ribe 2002, Findlay and Taylor 2006, Jähnig et al. 2011, Everard and Moggridge 2012, Seidl and Stauffacher 2013). How people relate to urban streams will differ among social groups (e.g., age, gender, socioeconomic status) and across different geographic extents (e.g., along the river network to globally; Ryan 1998, Williams and Stewart 1998, Matsuoka and Kaplan 2008). Individual relationships with urban streams may reflect sociocultural interactions that have little relationship to the stream itself (e.g., interpersonal interactions among members of the community) and can result from individual experiences at distant places other than urban streams (i.e., based on memories of and experiences in other places; Williams and Stewart 1998). Streams are remnant natural features in urban landscapes and, similar to other physical characteristics of built environments, they often reflect the sociopolitical character of cities in a positive and negative sense.

The importance of urban streams and riparian areas to local communities can be manifested in numerous ways (Wagner 2008). Ecological understanding of the structure and function of stream ecosystems is generally poor among local residents, and the characters that residents prefer or perceive as 'healthy' often do not match the current ecological state of the stream (Kaplan 1997, Mooney and Eisgruber 2001, Booth et al. 2004, Buijs 2009, Seidl and Stauffacher 2013, Winz et al. 2014), although preferences for certain components of streams (e.g., 'naturalness') may correspond to stream health (Junker and Buchecker 2008). Local communities often become more concerned with natural environments in their surroundings after environmental disturbances (Hunter 2011).

Larger rivers generally have a historical context in cities as central to commerce, industry, and transportation (e.g., municipal and industrial water supplies). The underlying shapes of metropolitan regions often reflect the banks of large waterways through urban landscapes (Spirn 1988). Large rivers are often more apparent within cities and more easily noticed by residents than smaller streams, which often are buried (Elmore and Kaushal 2008, Broadhead et al. 2013). Comparably fewer streams are found in urban than rural landscapes (Moran 2007), and remnant aboveground reaches often flow behind buildings and other infrastructure where they are inconspicuous and often neglected (Booth et al. 2004). Urban streams may either positively or negatively affect property values depending on their aesthetic and other physical properties (Kulshreshtha and Gillies 1993, Mooney and Eisgruber 2001). Streams are also often used as geographic boundaries, and may be viewed as important physical borders between neighboring communities with differing cultural or socioeconomic characteristics (Eden and Tunstall 2006).

DEFICIENCIES OF URBAN STREAM RESTORATION

Recognition of urban streams and rivers as valuable ecosystems that often possess pervasively degraded ecological states has led to diverse opinions about how to manage them in the face of increasing urban development. Large-scale sociopolitical movements aimed at restoring streams are generated by groups of people having the perspective that improving ecosystem structure and function has ecological and societal value (Eden and Tunstall 2006, Kondolf and Yang 2008). The discipline of restoration ecology has grown (Choi 2007), and its practice is becoming more common globally (Clewell and Aronson 2013). Current restoration frameworks range from specific (e.g., natural channel design; Rosgen 1996) to general (e.g., stream naturalization; Rhoads et al. 1999) and may include principles not linked to a particular environment (e.g., intervention ecology; Hobbs et al. 2011).

Reference-condition approach

The intent of restoration is to return the stream to some predisturbance condition, but the practitioners of urban stream restoration typically accept that regaining all structural and functional components of the predisturbance condition is unlikely (Booth 2005, Cockerill and Anderson 2014). Many project managers seek to remedy only specific issues (e.g., erosion, flooding) rather than the multiple issues needed for long-term structural and functional change (Palmer et al. 2014, Vietz et al. 2016). In either case, the target of most restoration projects for single or multiple issues is based on some reference condition indicative of a pristine or least-impaired state.

Approaches that attempt to return streams to a pristine or least-impaired state are particularly prone to failure when excessively erosive flows greatly modify geomorphic forms and processes, and channels are much larger than those of corresponding rural streams (e.g., Fig. 1; Choi 2007, Violin et al. 2011, Laub et al. 2012, Hawley et al. 2013, Vietz et al. 2014). Streams in urban landscapes often have irreversibly altered physical characteristics at small-to-broad spatial scales that prevent a return to natural hydrogeomorphic characteristics of reference conditions (e.g., unattainable channel slopes because of permanently altered local topographies; Wohl et al. 2005). Reference conditions for urban streams are often improperly characterized as single-thread systems with regular planform meanders and pool–riffle profiles, which is counter to the diversity of natural settings in plan (e.g., braided; Graf 1981) and profile (e.g., cascade, step–pool, forced pool–riffle; Montgomery and Buffington 1997). The need to protect local infrastructure (e.g., roads, bridges, sewer and stormwater pipes, houses, etc.) probably supports a bias toward characterizing reference condition as single-thread systems with stable channels and low structural variability. However, an understanding of the natural characteristics of streams in the region (i.e., the reference condition) is important for guiding project design and characterizing the success of stream restoration projects in urban settings. The disparities between realized project outcomes and expectations based on regional stream characteristics demonstrate the deficiencies of a reference-condition approach.

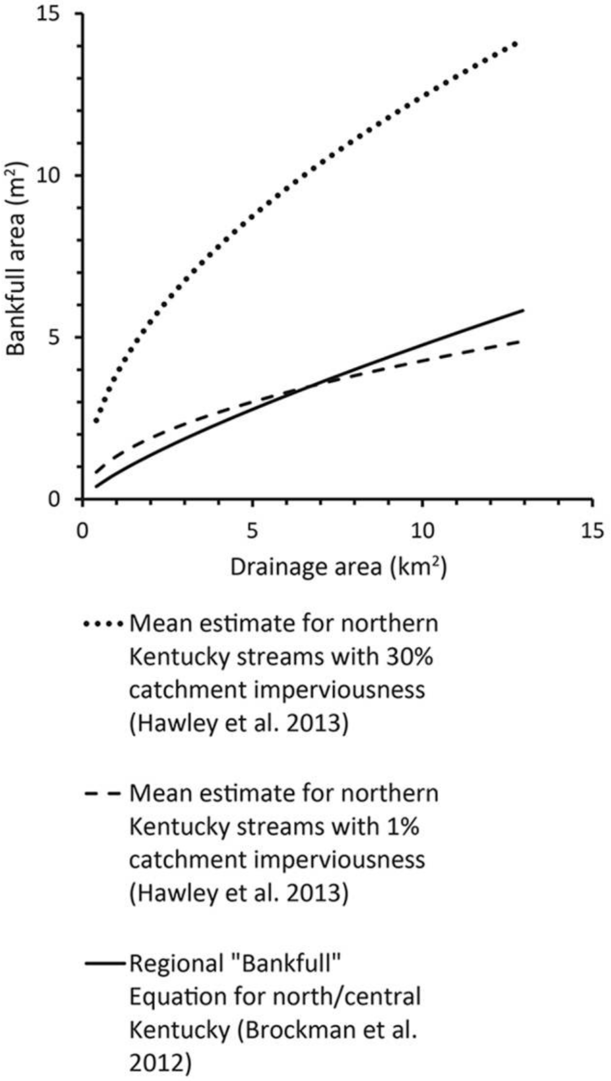

Figure 1. Relationship of bankfull area to drainage area for channels of undeveloped/reference streams and in urban catchments in northern Kentucky. All 3 curves increased predictably with drainage area, but area can be larger in urban than undeveloped or reference catchments (~2–3× larger for streams with 30% catchment imperviousness).

Legacy effects also limit the applicability of a reference-condition approach. Brown et al. (2009) identified antecedent land use as the most important explanatory factor in the response of streams to urbanization in the USA. The effects of altered land use on urban streams can persist long after the original stressors are removed (Harding et al. 1998, Cuffney et al. 2010, Hamilton 2012). In urban settings, the persistence and transformation of toxic chemicals in stream sediments (Meals et al. 2010; case study 4; Table 2, Appendix S1) and legacy agricultural sediments with elevated nutrient loads that can persist for several decades after land is taken out of production are particularly important (Dosskey et al. 2010, Meals et al. 2010). Legacy effects can also maintain channel forms that differ from predisturbance conditions (Walter and Merritts 2008).

Mismatch between temporal and spatial scale of effects and restoration projects

The temporal and spatial scales of restoration projects often are misaligned with the temporal and spatial scales of the causes of impairment (National Research Council 1999, Wohl et al. 2005, Naiman 2013, Cockerill and Anderson 2014). Reach-scale restoration projects are unlikely to affect water quality, the frequency of disturbance, or other functional or structural components of the stream system when human modifications to catchment landscapes are causing impairment (Hawley and Vietz 2016, Walsh et al. 2016). Reach-scale manipulations can affect ecosystem processes at small spatial scales, but many of the key processes affecting stream condition are controlled by properties of the catchment (e.g., hydrology, sediment, nutrient and organic-matter transport; Wohl et al. 2005, Imberger et al. 2011). As a result, catchment-scale manip-

Table 2. Summaries of 10 case studies that demonstrate how ecological and societal outcomes can be considered simultaneously in urban stream renovation projects (see Appendix S1). Emphasis describes whether outcomes: 1) were part of primary, secondary, or no project objectives, 2) resulted directly or indirectly from actions, and 3) occurred across broad or small spatial and temporal scales. A subjective measure on an ordinal scale describes the emphasis on ecological and societal outcomes based on the information available. This measure should be used only as a guide to investigate how a case study demonstrates ways to integrate ecological and societal outcomes. The codes are: 1 = indirect, not part of an objective, not planned or anticipated; 2 = indirect, part of a secondary objective, anticipated but minimally planned compared to the primary objectives; 3 = indirect, part of the primary objectives and required planning, but an indirect result of actions to accomplish the objective; 4 = direct, part of the primary objectives, accomplished by a single to few actions occurring over a small spatial scale (possibly a single reach); 5 = direct, part of the primary objectives, accomplished through multiple actions over a broad spatial scale (possibly catchment scale), required extensive planning.

Project/stream, location	Summary description	Emphasis[a]
1. Little Barrier Island, Auckland, New Zealand (LBI)	Island restoration: 100+-y restoration effort including reforestation, exotic species eradication, and limiting public access to 20 people/d.	Ecological: 5, societal: 1 (traditional restoration)
2. Little Stringybark Creek, Melbourne, Australia (LSC)	Watershed restoration (stormwater): 5+ y of disconnecting conventional stormwater drainage from Little Stringybark Creek using rainwater harvesting strategies.	Ecological: 5, societal: 2
3. Urban stream restoration, Portland, Oregon, USA (USP)	Prioritized reach-scale restoration: implementation of 4 reach-scale habitat projects based on watershed-scale understanding of aquatic and riparian habitat, fish passage, channel erosion, water quality, and impacts on public infrastructure.	Ecological: 5, societal: 3
4. Hagbygärdediket, Kalmar, Småland, Sweden (HAG)	Pond/wetland-based water quality reclamation: construction of 3 large ponds/wetlands to reduce nutrients, metals, and organic compounds from a heavily urbanized and previously untreated catchment draining to the Baltic Sea via Hagbygärdediket, designed with recreational, ecological, and cultural objectives.	Ecological: 4, societal: 4
5. Donnybrook and Hollywood Branch, Montgomery County, Maryland, USA (DHB)	Sewer, stormwater, and reach-scale restoration: multifaceted projects to address water quality, stream erosion, habitat, and ecological objectives in urban watersheds that incorporated stakeholder engagement and input for prioritization and design.	Ecological: 4, societal: 5
6. Lick Run, Cincinnati, Ohio, USA (LKR)	Stream daylighting, stormwater, and sewer overflow mitigation: publicly supported watershed approach to combined sewer overflow mitigation that included stormwater disconnection, capture, and treatment via stormwater control measures, and ~3.2 km of stream habitat reconstruction of reaches that had been buried for >100 y.	Ecological: 3, societal: 5
7. River Quaggy, London, UK (RQY)	Stream remeandering in urban park: 500-m habitat restoration project, including flood storage ponds, riparian area naturalization, and public education signage with limited ecological recovery because of upstream sewer misconnections or unmitigated combined sewer overflows.	Ecological: 3, societal: 4
8. Boulder Creek, Boulder, Colorado, USA (BCR)	Flood mitigation and greenway: the flood mitigation project primarily involved purchasing adjacent property and enlarging the channel, but also incorporated development of a greenway and construction of some in-channel habitat features.	Ecological: 2, societal: 4
9. Gum Scrub Creek, Melbourne, Australia (GSC)	Constructed flood-control waterway: provides flood control through a new development that included a mix of inset rock-lined and natural channels, a 100-m-wide riparian zone, native plantings, and is an aesthetic amenity for the development.	Ecological: 2, societal: 4
10. Quebrada Ortega, Quito, Ecuador (QBO)	Riparian sanitation: 12-y riparian recovery project to remove trash/debris, install landscaping and recreational facilities along riparian zones of streams in Quito.	Ecological: 1, societal: 5

ulations are being developed to address causes of impairment to urban streams (e.g., Walsh et al. 2009), and researchers and managers in several regions are pursuing approaches that address in-channel and catchment-scale drivers of impairment (e.g., City of Portland 2005, Hawley et al. 2012, Rios-Touma et al. 2015). In addition, causes of impairment that operate outside of catchment boundaries (e.g., dispersal barriers, atmospheric deposition, climate change) may require action at broad spatial scales that are difficult to accomplish (Bond and Lake 2003, Kaye et al. 2006, Hughes 2007, Nelson et al. 2009).

Lack of integrating societal benefits

The lack of integration of societal considerations often is regarded as one of the key reasons for the failure of restoration efforts, especially in urban systems (Eden and Tunstall 2006, Naiman 2013, Yocum 2014). A lack of stewardship and support by surrounding urban communities and local governments can hinder the ecological success of a project with long- and short-term goals (Booth 2005, Yocum 2014). As a result, recent frameworks in restoration ecology have highlighted a need to: 1) incorporate societal benefits, 2) promote a sense of stewardship by local communities, and 3) include multiple stakeholders in the design, implementation, and assessment of restoration projects (e.g., Booth et al. 2004, Palmer et al. 2005, Clewell and Aronson 2006, Petts 2006, Kondolf and Yang 2008, Hager et al. 2013).

A potential shortcoming of many contemporary approaches is that societal benefits are often opportunistic or indirect outcomes of actions intended to achieve ecological improvements (Booth et al. 2004, Clewell and Aronson 2006, Kondolf and Yang 2008, Hager et al. 2013). Hesitancy to incorporate actions with the primary purpose of generating societal outcomes may result from: 1) the complexity of interactions among ecological and societal contexts (described above), 2) the potential opportunities for spurious conclusions about project success without ecological evidence (e.g., a project deemed a success based on surveys showing high local community satisfaction despite little ecological improvement; Bernhardt and Palmer 2007), or 3) purposeful acts akin to a form of ecological 'greenwashing' (superficial actions to deal with substantial ecological and societal impairment; Beatley 2011).

URBAN STREAM RENOVATION

We define *urban stream renovation* (USR) as a unifying framework that incorporates ecological and societal outcomes (Table 1) to achieve long-term ecological improvement to stream ecosystems. The USR framework incorporates 2 evolving perspectives in restoration ecology: 1) restoration should more fully incorporate potential societal benefits (Clewell and Aronson 2006, Eden and Tunstall 2006, Ramalho and Hobbs 2011,Yocum 2014) and 2) restoration goals should be flexible and align more with future scenarios than past conditions (i.e., less focus on a reference-condition approach; Choi et al. 2008, Hobbs et al. 2011). We think that these 2 perspectives can potentially lead to an expanded set of beneficial outcomes. From a practical perspective, USR incorporates core restoration concepts: 1) stating objectives clearly, 2) mandating that the best remaining habitats be protected, and 3) examining ecosystem structure and function (US National Research Council 1992, Roni et al. 2002, Bernhardt and Palmer 2007, Palmer and Febria 2012). The USR framework is not constrained by reference conditions, but the framework allows incorporation of characteristics of local natural environments to support project design and evaluation when appropriate (e.g., Violin et al. 2011, Rios-Touma et al. 2015).

We posit that if projects are designed properly, short-term actions intended to achieve societal benefits can result in increased public support for actions to achieve short- to long-term ecological improvements to urban streams. Positive interactions of people with natural areas can promote an affinity for the environment and its conservation and improvement (Spirn 1988, Purcell et al. 2002, Turner et al. 2004, Beatley 2011, Özgüner et al. 2012). The USR framework uses increased flexibility for setting ecological and societal objectives (by avoiding an ecologically focused reference-condition approach) to achieve additional ecological and societal outcomes. The increased stewardship and public support for stream improvement resulting from additional societal benefits can generate a feedback loop in which communities and governments allocate public resources to support successive ecological or societal actions (Fig. 2; Rogers 2006). This iterative process can be designed so that the cumulative effect of manageable short-term ecological outcomes can accomplish improvements of stream ecosystem structure and function at broad spatial and temporal scales that potentially could be used to address catchment-level drivers of stream degradation (Hermoso et al. 2012, Palmer et al. 2014).

From a societal perspective, the short-term and small-scale projects that compose this iterative process are highly suited for generating community support for broader initiatives (Yocum 2014). Some residents may have difficulty seeing links between small-scale actions, catchment processes, and overall stream health. However, practitioners can combine reach-scale activities with outreach and education to inform the public about the benefits of additional actions throughout the catchment (Church 2015). The case study for Donnybrook and Hollywood Branch (Table 2, Fig. 3, Appendix S1) shows how continued outreach to the community currently is supporting catchment-level alterations that followed reach-level projects.

The incremental approach we present must be systematic and should not take the form of a piecemeal approach to improving stream ecosystems (Hermoso et al. 2012). Urbanization is a long-term, severe press disturbance that profoundly alters the biotic and abiotic components of streams and rivers (Paul and Meyer 2001). The process of improving the structure and function of urban stream ecosystems is a similar long-term, gradual process of coordinated landscape modifications at small and broad spatial scales. USR efforts are expected to be long term because of

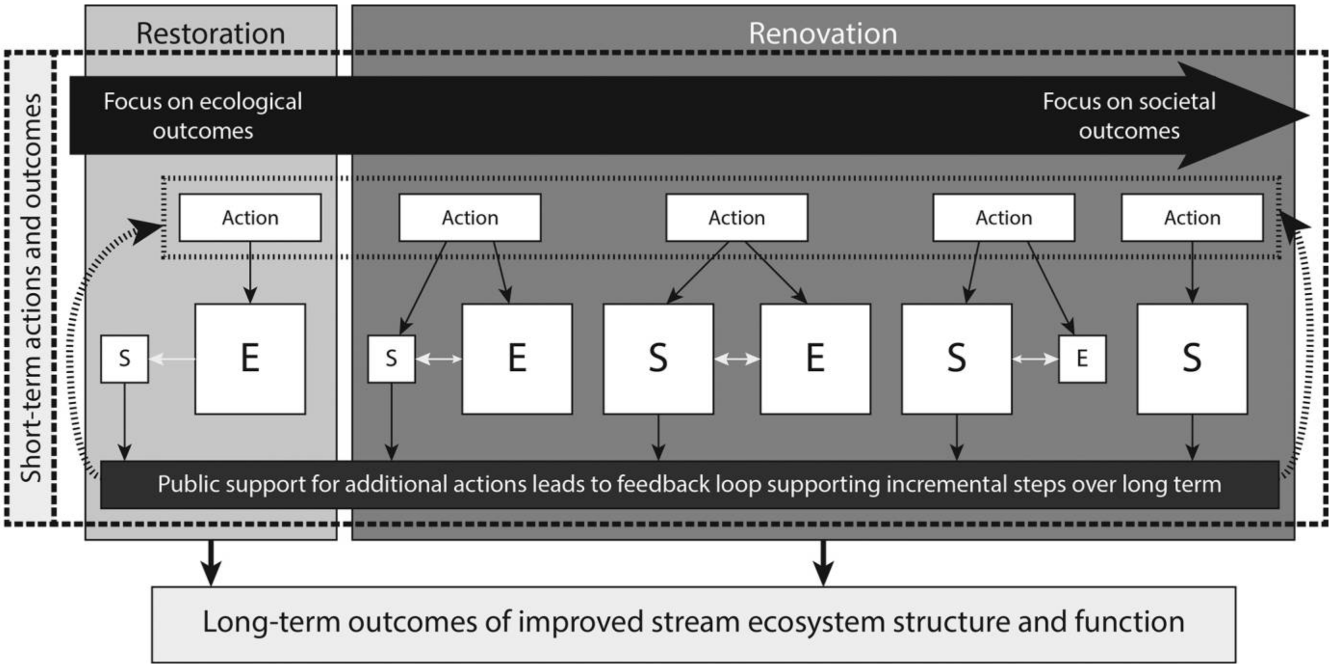

Figure 2. Conceptual diagram showing how short- and long-term outcomes are linked and the relative emphasis of ecological (E) and societal (S) outcomes along a gradient. Actions and outcomes in support of short-term objectives are surrounded by a box with a thick, dashed border. Large boxes indicate a primary objective, and small boxes indicate a secondary objective (or not an objective for restoration; see Table 2). Projects with primary E and S objectives (equal-sized boxes) are ideal. White arrows connecting E and S outcomes demonstrate how they are integrated and that outcomes may occur as an indirect effect (unequal arrow heads). We represent S outcomes in traditional restoration as a secondary effect of the ecological outcome, but some modern approaches are integrative (see Little Barrier Island, Auckland, New Zealand example, Table 2). Black arrows between S and the box representing public support begin the feedback loop supporting additional actions. Actions leading to only S outcomes (far right) can support urban stream renovation (USR) through feedbacks, but care should be taken to ensure that it will support long-term ecological outcomes. S outcomes that do not contribute to feedback loops are not part of USR and were omitted.

the severe nature of urban damage. Thus, practitioners face the difficult task of maintaining public support over long time scales to achieve long-term ecological outcomes (see below).

The USR framework aligns with several concepts of intervention ecology including: 1) a flexible approach to managing ecosystems for future states rather than past (i.e., reference) conditions, 2) explicit consideration of the site's history, and 3) an interdisciplinary approach incorporating ecological and social sciences (Hobbs et al. 2011). However, the USR framework differs from intervention ecology by: 1) considering future, current, and past ecological and societal conditions rather than focusing on the ecology, 2) integrating ecological and societal contexts rather than nesting ecological within societal contexts, 3) addressing societal support (e.g., stewardship, policy) directly through societal outcomes rather than extraneous actions, and 4) integrating ecological and societal components further through an iterative process that relies on feedbacks among outcomes generated from short-term actions (Fig. 2). In addition, the temporal aspect of the USR framework, whereby ecological and societal outcomes can be realized at different points in time, and the setting of clear a priori objectives for ecological and societal outcomes are what differentiate it from naturalization (see Rhoads et al. 1999). A criticism of intervention ecology is that the flexibility to set objectives that do not conform to reference conditions and the integration of societal outcomes may limit overall ecological benefits (Palmer et al. 2014). However, we think that the iterative approach and the requirement that all societal objectives support actions to achieve long-term ecological outcomes are consistent with the framework's intended use as an integrative approach that does not sacrifice ecological benefits.

Integrating societal objectives

Cities across the globe have a wide range of histories and conditions that affect the social connection to, and support for, efforts to improve streams. USR may be an adaptable approach to use across this range of socioeconomic settings. We expect outcomes to vary among cities in response to differing histories, conditions, and connections. For example, a centuries-old city like Quito, Ecuador, where untreated sewage discharges, flood debris, and trash

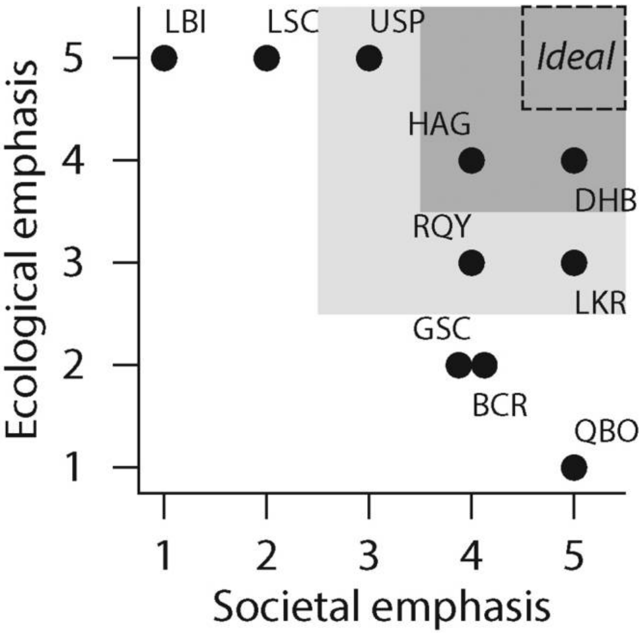

Figure 3. Plot showing the relative emphasis on ecological (E) and societal (S) outcomes for the 10 case studies presented in Table 2 and Appendix S1. See Table 2 for 3-letter case-study codes and descriptions of the categories on each axis. The light gray box indicates projects with E and S primary objectives, the dark gray box indicates projects with actions that directly resulted in E and S outcomes, the dashed box labeled ideal indicates projects with E and S primary objectives, actions with direct effects on all outcomes, and outcomes of both types occurring over broad spatial and temporal scales. No case study was classified as ideal.

accumulation are major stressors to river health, might first prioritize trash removal and the treatment of sewer discharges. This step would allow rivers and streams to transition from being viewed as unsightly human health threats to recreational, ecological, and aesthetic amenities (Table 2). Future initiatives taking a comprehensive approach to improving stream and river ecological health might be supported and implemented as the community's affinity for local streams and rivers slowly increases. In contrast, sewage and stormwater treatment have progressed in relatively young cities like Portland, Oregon (USA), and improvements to water quality are supported, in part, by the populace's strong cultural connection to the local rivers and their iconic residents, salmon (Table 2). Improving urban streams is critical to regional salmon recovery because the city is situated near the mouth of the Columbia River, which was historically one of the greatest salmon rivers in the world (McConnaha et al. 2006). The progression toward improved urban stream health might be more rapid and might reach a greater level of improvement in young cities like Portland than in older cities with similar cultural connections to local rivers. These examples highlight how: 1) geographic and historical contexts of cities interact to influence environmental degradation and are important for assessing the feasibility and trajectories of long-term ecological and societal improvements (Yocum 2014) and 2) the process of urbanization differs among cities of different ages and generates variability in societal and ecological contexts among urban areas (Pickett and Zhou 2015).

The same factors that determine an individual's relationship with urban streams will affect their perceptions of USR projects. Ecological and societal perspectives are colocated and may interact in urban landscapes (Cockerill and Anderson 2014). Thus, ecological and societal contexts should be integrated but should account for different perspectives and goals for improving stream environments among stakeholders (e.g., Funtowicz and Ravetz 1993, McDonald et al. 2004, Smith et al. 2014). The use–value concept proposed by Hillman et al. (2011) describes potential or actual links between people and the river environment based on how human groups appreciate or use the river. Therefore, these use–values are understood as culturally specific and demonstrate how societal–ecological links are context dependent (Palmer 2006).

Local residents may value certain nonecological outcomes (Cockerill and Anderson 2014). For example, aesthetics are often considered the most important component of restoration projects by local communities (Buijs 2009, Özgüner et al. 2012), and public support for projects generally increases when aesthetic preferences are incorporated into project designs (Hunter and Hunter 2008). Thus, aesthetics may be important for maintaining long-term public support. Ideally, projects can improve ecosystem function while promoting the aesthetics of channel and riparian forms, but accomplishing both with a single action may not be feasible. The case study for Cincinnati, Ohio (USA) (Table 2, Fig. 3, Appendix S1) demonstrates how calibrating an urban channel design to incorporate aesthetic properties desired by the community can be done without sacrificing environmental objectives. Aesthetic preferences vary among people, and they may be influenced by landscape and regional environmental settings that cannot be altered (e.g., preference for a mountainous landscape surrounding the city; Asakawa et al. 2004). Moreover, practitioners should be careful that actions resulting in societal outcomes, particularly those increasing the aesthetic value of streams, do not skew stakeholders' subjective interpretations of what a healthy stream 'looks like' by promoting an affinity for stream reaches with little ecological integrity (Cockerill and Anderson 2014).

Role of adaptive management

Adaptive management should be applied to short-term actions and across successive project iterations to reach long-term ecological objectives (Fig. 2). Adaptive management can improve ecological outcomes by adjusting protocols in response to environmental change, unforeseen environmental responses, new methods, and other factors that limit the effectiveness of current approaches. Changes in attitudes and values of the local community and political entities occurring over long time frames can be substantial barriers to long-term project success (Spirn 2005, Eden and Tunstall 2006). Thus, adaptive management to counteract potentially pervasive, swift, and broad changes in stewardship, public support, and financial support will be crucial for achieving long-term ecological outcomes. At the very least, adaptive management can help accommodate the intended increase in public support resulting from societal outcomes.

Implementation

The emphasis on ecological and societal outcomes for short-term actions occurs along a gradient (Table 2, Fig. 2). The emphasis given to each type of outcome should result from scientist, manager, local community, and other stakeholder inputs based on the ecological and societal contexts of the region. The only requirement is that project designs link short-term ecological and societal outcomes to long-term ecological objectives. Preferably, short-term actions will include primary objectives with ecological and societal goals that incorporate actions and outcomes occurring over broad spatial and temporal scales (Table 2, Figs 2, 3).

However, situations may arise where the emphasis should be placed on either ecological or societal outcomes (Fig. 2). Prioritization of ecological or social outcomes would be defined ideally on the basis of empirically tested, standardized methods. Short-term actions should also be designed to maximize indirect outcomes when possible (Fig. 2; Kondolf and Yang 2008). However, this approach potentially requires that project planners accept an emphasis on short-term societal outcomes, provided they are part of a strategy for achieving long-term ecological objectives. The case studies presented in Table 2 and Appendix S1 (also see Fig. 3) provide examples of the various ways that improvement projects can emphasize ecological and societal outcomes and specifically how each: 1) can result directly or indirectly from actions, 2) may or may not be primary objectives of projects, and 3) can occur over different temporal and spatial scales.

Incorporating societal outcomes to the extent proposed for the USR framework is likely to generate the same concerns about potential abuses that typically accompany integrative frameworks. The framework's central rule is that all societal objectives must be couched within a larger coordinated effort to support short- to long-term ecological outcomes. We present several additional points of emphasis for preserving this central rule that we think will limit its misuse.

1. Predetermined short- to long-term objectives must be properly documented, agreed upon, and maintained throughout the project. Stakeholders should not use this framework as a way to claim 'success' retrospectively for projects with poorly defined objectives.
2. Specific procedures within the stakeholder group must be agreed upon before projects are implemented but should allow for adaptive management in response to unexpected situations. A priori thresholds that trigger alternative strategies must be decided upon prior to project implementation whenever possible. All stakeholders must be informed and must agree to changes resulting from adaptive management during short and long time frames.
3. Inclusion of societal outcomes should not be used as a means to justify ignoring legal obligations to maintain a healthy ecosystem. However, societal benefits are an implied outcome of a successful renovation project. Thus, monitoring societal outcomes as part of this framework can provide a direct assessment of the realized societal benefits of the specific actions used to comply with environmental regulations.
4. The framework should not be applied to situations where ecological objectives are knowingly unattainable. Actions with no intention of supporting any ecological outcomes at any scale are a sociocultural exercise that falls outside the USR framework. In addition, societal outcomes should not reduce the potential for ecological outcomes in the future (e.g., hard channel lining to increase public access).
5. Integration of ecological and societal components should be complete and should occur throughout the project for the framework to function properly. However, the ability to integrate them will depend on the knowledge of those implementing the project and the available resources (Rogers 2006).

Regardless of the emphasis on ecological and societal outcomes, any project that seeks to improve urban streams will require high levels of interaction among people and has a high potential for conflicts (Eden and Tunstall 2006). Conflicts can be limited when project design incorporates effective strategies for gathering and deciphering diverse opinions from stakeholders (e.g., structured decision making; Gregory et al. 2012). Conflicts may exist among various stakeholder-group preferences, and they may exist between stakeholder and professional preferences focused on improving ecological conditions (Eden and Tunstall 2006, Pahl-Wostl 2006). Managers also must try to avoid negative feedbacks that diminish public support (e.g., long-term maintenance procedures that have adverse societal impacts). This sensitivity includes being aware of the potential for gentrification of urban areas after broad-scale environmental improvements (Wolch et al. 2014).

GENERALIZATIONS

The goal of any standardized framework is to increase the ability to make generalizations that may otherwise be difficult to make across projects because of differences in ecological or societal contexts. New integrative approaches to managing water quality, such as the European Union Water Framework Directive (EU-WFD; European Union 2000), requires applicability across broad spatial and temporal scales. The USR framework aligns with the EU-WFD's: 1) use of an integrative approach, 2) focus on catchment-level processes of impairment, 3) reliance on local stewardship, and 4) focus on education and outreach. Regardless of the need to make generalizations, implementation must take into account potential regional and global differences in the ecological and societal characteristics of urban systems and how they interact (Cabin 2007, McHale et al. 2015, Pickett and Zhou 2015, Booth et al. 2016, Capps et al. 2016). We developed the USR framework to be specifically applicable to urban landscapes and intentionally avoided discussion of lentic environments, which may be integral to broad management directives.

RECOMMENDATIONS AND FUTURE DIRECTIONS

The case studies (Table 2, Fig. 3, Appendix S1) demonstrate that ecological and societal objectives can be incorporated together in varying degrees when attempting to improve the structure and function of stream ecosystems. Insights can be drawn from examples like these, but methods for achieving short- and long-term outcomes must be tested and critiqued. The need for future work is particularly important for identifying how best to integrate ecological and societal outcomes as advocated in our paper. In developing this framework, we identified several areas where future research is needed to inform its development and improve its implementation.

Defining methods to assess societal outcomes

The USR framework requires methods to assess societal outcomes quantitatively (Eden and Tunstall 2006). Many suitable measures exist in social science, economics, public health, and other disciplines, but a thorough analysis of the applicability of existing measures to USR projects is needed (Eden and Tunstall 2006). New methods specific to the framework also may have to be developed. Empirical studies examining the effectiveness of these measures are preferred over expert opinion, but development should draw upon the discipline within which the measure originated. Sociocultural characteristics of local populations and physical characteristics of landscapes affect each other (i.e., as feedbacks) to form contemporary societal and ecological contexts of human-dominated landscapes (Nassauer 1995). Thus, societal assessments must account for potential interactions with ecological contexts (and vice versa).

Most stream improvement projects fail to generate useful ecological monitoring data despite the fact that monitoring is accepted as critical for project success (Bernhardt et al. 2005). Remedying this deficiency is particularly important for the USR framework, but the priority to incorporate proper monitoring should be extended to include ecological and societal assessments. One reason for a lack of monitoring is that many stream-improvement projects are conducted without proper scientific input, and projects are designed with minimal consideration of the complexities of stream ecosystems that affect project success (Wohl et al. 2005). This deficiency often results in a vast divide between project objectives and the monitoring plan (Z. K. Rubin and G. M. Kondolf [University of California], BR-T, and M. E. Power [University of California], unpublished data). Societal monitoring also must occur over long enough time scales to assess societal outcomes. For example, in the same way that channel and riparian manipulations are disturbances that can cause short-term decreases in biotic integrity followed by long-term recovery (Muotka et al. 2002), community perceptions of urban streams may be unfavorable immediately following physical manipulations and improve over time as the stream recovers (Åberg and Tapsell 2013). Monitoring regimes also may have to be altered to deal with the incremental approach in which short-term outcomes are used to achieve long-term objectives. However, we think that increased local stewardship could lead to citizen-scientist monitoring programs, which could expand monitoring and improve assessments of project success (Lepori et al. 2005, Naiman 2013, Smith et al. 2014, Rios-Touma et al. 2015).

Education and outreach

The USR framework depends on education of and outreach to local communities. Outreach and education should be considered a component of project design with the specific roles to: 1) solicit support by the community for project activities and 2) alter the values of local communities to develop a sense of long-term stewardship (Williams and Stewart 1998, Egan et al. 2011). Community engagement must be proactive and designed to maintain a sense of stewardship over long periods of time. Similar to preproject biological assessments, the societal context of sites should be assessed before project implementation to decide how to begin the project with stakeholder support and incorporate additional stakeholders during the project (Seidl and Stauffacher 2013). The most effective ways to communicate with and involve stakeholders typically will differ among individuals (Tunstall et al. 2000).

Easy-to-follow methods for effective outreach and education are needed by managers and scientists who do not have a background in community engagement. Developing empirically based strategies for education and outreach that: 1) are science-based (ecological and social), 2) are specific to urban systems, 3) address different demographics, and 4) incorporate modern technology would augment strategies developed from the experiences of agency personnel and other practitioners (Hudson 2001, Groffman et al. 2010). Education and outreach strategies should draw from concepts in environmental education (see examples in Hudson 2001) and avoid methods stemming from a 'deficit model' based on the assumption that a lack of public support stems from scientific illiteracy (Eden and Tunstall 2006, Groffman et al. 2010). Moreover, approaches for outreach to policy makers may differ from on-the-ground outreach in local communities but should be incorporated into societal outcomes.

USR projects also are likely to benefit from incorporating outreach activities that differ from traditional environmental education (e.g., to address logistical issues such as public support, land access). The Montgomery County, Maryland, Department of Environmental Protection (MC-DEP), which conducted the Donnybrook and Hollywood Branch restoration (Appendix S1), has developed draft procedures for education and outreach during restoration projects based on experiences from past projects. In addition to themes from general environmental education, their procedures include activities to build relationships with local communities that are not primarily educational activities (e.g., a ribbon-cutting ceremony). Education and outreach activities are likely to take on many forms, and project members should design activities that combine education with other project objectives whenever possible (e.g., education of citizen scientists as part of a monitoring program: Middleton 2001; incorporating educational institutions, such as visitor centers and museums, within complex socioecological management strategies: Olsson et al. 2007).

Generating multidisciplinary collaborations

Development and implementation of the USR framework will require multidisciplinary research with equal contributions from ecological and social science backgrounds. Multidisciplinary teams could include social scientists, landscape designers, architects, economists, lawyers, and public health officials in addition to individuals from multiple subdisciplines in stream ecology (e.g., hydrologists, entomologists, geochemists, fisheries biologists, etc.). Collaborations can be developed through educational institutions, professional societies, or opportunities for cross-disciplinary synthesis projects. In addition to developing empirical methods for achieving short- and long-term outcomes, multidisciplinary teams also are needed to effectively guide integrative adaptive management strategies. Ideally, these teams should be maintained throughout the project.

Multidisciplinary collaborations also may help the USR to promote broader ecological and societal benefits beyond improving urban streams. For example, projects that increase green spaces and the naturalness of urban areas (e.g., part of broad-scale biophilic landscape designs) can: 1) lead to public support of general environmental initiatives (e.g., climate change), 2) encourage individual activities by residents that benefit the environment (e.g., reduced automobile use), 3) promote human well-being (human health, economics, social justice, and education), or 4) encourage further study in ecology by residents of urban communities who may typically be underrepresented in science, technology, engineering, and math (STEM) fields (Spirn 2005, Matsuoka and Kaplan 2008, Beatley 2011, Bunch et al. 2011, Russell et al. 2013).

We think that the multidisciplinary nature of the USR framework also can help project managers draw from a larger potential funding/support base than would be available for projects with fewer societal considerations. Multidisciplinary collaborations may lead to new or creative funding opportunities by providing opportunities to develop projects with the broader impacts described above. Moreover, scientists studying the biological, chemical, and geomorphological characteristics of streams can look for opportunities to conduct experiments that mix ecological and societal objectives by partnering with landscape architects, urban designers, and local residents (e.g., through 'urban design experiments'; Felson et al. 2013). Collaborating with public works offices may lead to novel designs of public works projects that achieve ecological and social benefits at a lower cost than separate projects carried out in isolation (Hawley et al. 2012). In addition, leveraging resources used for public works projects can provide dual benefits to the stream environment and the local community (Donnybrook and Hollywood Branch, Urban Stream Restoration; Table 2, Appendix S1).

CONCLUSION

The USR framework recognizes that ecological and societal objectives are intrinsically linked. Even though the framework explicitly incorporates societal objectives and goes as far as emphasizing short-term societal outcomes over ecological ones, its end result is focused on improving the ecological state of urban streams. We think the end results of the framework can be: 1) increased opportunities for achieving beneficial outcomes, 2) greater societal support for improving urban streams, 3) fewer conflicts between ecological and societal factors, and 4) opportunities to address catchment-level drivers of stream degradation.

A substantial challenge to implementing the USR framework may be the adoption of integrative approaches by project leaders. Multidisciplinary approaches have logistical and conceptual challenges. Learning how to assimilate information from and communicate with collaborators from other disciplines and the general public is difficult (Groffman et al. 2010). Stream ecologists must avoid the comfortable choice of defaulting to an emphasis on ecological objectives.

Some urban stream ecologists may argue that considering societal outcomes to the extent we advocate will limit ecological improvement. We acknowledge that actions to achieve societal outcomes require resources (time, money, etc.) that could be used for actions to achieve ecological outcomes directly (Palmer et al. 2014). While admittedly untested, we believe that societal outcomes can be accomplished without sacrificing ecological objectives, and greater societal support can help accomplish ecological outcomes that would otherwise be unattainable (Fig. 2). The USR framework is based on the idea that resource allocation to societal objectives can have a net ecological benefit for urban streams by increasing public awareness and support for broader environmental issues. The USR framework requires testing, but an understanding of how to integrate societal and ecological objectives in projects to improve urban streams clearly is needed to support all emerging integrative approaches. Our hope is that critiques of this framework lead to methods that effectively incorporate societal outcomes as a means to improve the ecosystem structure and function of streams in urban landscapes.

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A Review of Urban Water Body Challenges and Approaches: (1) Rehabilitation and Remediation

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ABSTRACT: *We review how urbanization alters aquatic ecosystems, as well as actions that managers can take to remediate urban waters. Urbanization affects streams by fundamentally altering longitudinal and lateral processes that in turn alter hydrology, habitat, and water chemistry; these effects create physical and chemical stressors that in turn affect the biota. Urban streams often suffer from multiple stressor effects that have collectively been termed an "urban stream syndrome," in which no single factor dominates degraded conditions. Resource managers have multiple ways of combating the urban stream syndrome. These approaches range from whole-watershed protection to reach-scale habitat rehabilitation, but the prescription must be matched to the scale of the factors that are causing the problem, and results will likely not be immediate because of lengthy recovery times. Although pristine or reference conditions are far from attainable, urban stream rehabilitation is a worthy goal because appropriate actions can provide ecosystem improvements as well as increased ecosystem service benefits for human society.*

Revisión de Enfoques y Retos en el Estudio de Cuerpos de Agua Urbanos: (1) Rehabilitación y Remediación

RESUMEN: *se hace una revisión de cómo la urbanización altera los ecosistemas acuáticos, así como también de las acciones que los administradores pueden tomar para remediar el problema de las aguas urbanas. La urbanización afecta los ríos a través de la alteración de procesos longitudinales y laterales que, a su vez, modifican la hidrología, hábitat y química del agua; estos efectos crean factores químicos y físicos de estrés que perturban la biota. Los ríos urbanos suelen estar sujetos a múltiples factores de estrés que colectivamente se conocen como "síndrome del río urbano" en el cual no existe dominancia de un solo factor de degradación. Los administradores de recursos naturales tienen diversas formas de combatir este síndrome. Estos enfoques van desde protección de cuencas enteras hasta rehabilitación de hábitats a gran escala, pero la prescripción debe ser consistente con la escala de los factores que están causando el problema, y es probable que los resultados no sean inmediatos dado que los tiempos de recuperación son prolongados. A pesar de que se está lejos de poder reconstruir las condiciones prístinas o de referencia, la rehabilitación de los ríos urbanos es un objetivo digno de perseguir ya que la toma de acciones adecuadas pueden lograr mejoras a los ecosistemas así como también un incremento en los beneficios que la sociedad humana obtiene de ellos.*

PREFACE

This article and its companion (Hughes et al., 2014) stem from two reports published by Oregon's Independent Multidisciplinary Science Team (IMST 2010, 2012). The IMST was established by Oregon Revised Statute 541.409 in 1997 to provide independent, impartial advice to the state on scientific matters related to the Oregon Plan for Salmon and Watersheds. Previous IMST reports and agency reviews had focused on forest and agricultural land uses, and most of the rehabilitation efforts in the state were focused on those landscapes because of their great extent. The IMST recognized, however, that (1) most Oregon citizens live in cities and rural residential areas, (2) many important salmonid streams and rivers pass through those urban areas, and (3) urban areas play a key role in salmonid rehabilitation. Therefore, IMST (2010) was written to evaluate the science and how actions in urban and rural residential areas might aid salmonid recovery and catchment condition. Following completion of IMST (2010), the IMST held a workshop composed of municipal and state environmental managers and practitioners in 2011 to help fill gaps existing between the published scientific literature and what is known and needed by professionals actively working to rehabilitate aquatic resources in Oregon urban and rural residential areas. IMST (2012) summarized what was learned at that workshop and stimulated these two *Fisheries* articles, as well as a book (Yeakley et al., 2014).

INTRODUCTION

Human societies alter water bodies, the effects of which are dependent on the relative sizes of the urban centers versus the water bodies, their industries, and the natural and historical setting of the city. Because most people now live in cities and water is critical to human health and well-being, it is vital to maintain water quality in socially, economically, and ecologically effective ways. Although ecological effects of urbanization on aquatic ecosystems are described well in the scientific literature, approaches for rehabilitating and mitigating problems have received less attention and have not been considered in a practical, integrated manner. We review and summarize various approaches for reducing the effects of current urbanization on surface waters and discuss their benefits and limitations. Our review is divided into two major sections: (1) effects of urbanization on aquatic ecosystems and (2) actions for rehabilitating aquatic ecosystems in existing urban areas.

Urbanization results in a phenomenon commonly known as the “urban stream syndrome,” whereby hydrographs become flashier (i.e., increased flow variability), water quality is degraded, channels are homogenized and incised, biological richness declines, and disturbance-tolerant and alien species increase in prevalence.

EFFECTS OF URBANIZATION ON AQUATIC ECOSYSTEMS

Understanding the effects of urbanization, or any land use, on aquatic ecosystems requires consideration of local- and catchment-scale effects, as well as current and historical effects. Civilizations began with cities around 9,000 YBP in the Middle East and China and 3,000 YBP in Mesoamerica. Many were hydraulic societies that modified their aquatic systems. This review, however, focuses on cities developing within the past 200 years. With over 50% of the world’s population living in cities, and trending higher, urbanization is a global phenomenon (United Nations Population Division 2006; Grimm et al. 2008); 80% of U.S. citizens live in urban areas (Coles et al. 2012). High urban population density reduces the transportation cost of goods and services, offers greater employment opportunities, and increases information exchange that supports education and cultural enrichment (Grimm et al. 2008). However, urban areas fundamentally alter aquatic ecosystems—especially their hydrology, water quality, physical habitat quality, hydrological connectivity, ecological processes, and biota (Paul and Meyer 2001; Brown et al. 2005; Walsh et al. 2005; Chin 2006; Kaye et al. 2006; IMST 2010; R. A. Francis 2012; Yeakley et al., 2014). These multifactor stressors and complex ecosystem responses are called “syndromes” (Rapport et al. 1985; Regier et al. 2013). Urbanization results in a phenomenon commonly known as the “urban stream syndrome” (Walsh et al. 2005), whereby hydrographs become flashier (i.e., increased flow variability), water quality is degraded, channels are homogenized and incised, biological richness declines, and disturbance-tolerant and alien species increase in prevalence. This syndrome may begin under even low levels of disturbance; for example, Stanfield et al. (2006) and Stranko et al. (2008) found that only 4%–9% impervious catchment cover sufficed to eliminate salmonids from Ontario and Maryland streams. Residential development also simplifies the riparian and nearshore zones of lakes by installing retaining walls and by reducing riparian vegetation, shoreline complexity, and snags (Jennings et al. 1999, 2003; T. B. Francis and Schindler 2006), which in turn alter fish and macroinvertebrate assemblages (Whittier et al. 1997; Jennings et al. 1999; Brauns et al. 2007). Watershed damage occurs because urbanization alters catchment hydrology (Groffman et al. 2003; Walsh et al. 2005), soil conditions (IMST 2010), vegetation composition and cover (Booth et al. 2002), atmospheric chemistry (Kaye et al. 2006; Grimm et al. 2008), elemental mass balances and cycling (Groffman et al. 2003; Hook and Yeakley 2005), and riparian corridors (Bryce et al. 2002; Hennings and Edge 2003; Ozawa and Yeakley 2007). These alterations result in an urban land syndrome with simplified, compacted, and more mineralized soils having lower water retention capability, increased atmospheric deposition of pollutants, and replacement of natural vegetation structure with anthropogenic structures and impervious surfaces, culminating with replacement of native biota by alien taxa tolerant of anthropogenically altered ecosystems (Grimm et al. 2008). In nine cities studied by Coles et al. (2012), these terrestrial changes consistently resulted in loss of sensitive taxa, beginning at the earliest stages of urbanization (i.e., no resistance to low levels of development). Biological degradation continued at the highest levels of urbanization studied (i.e., no exhaustion threshold), suggesting that resource managers could obtain biological benefits from any appropriate rehabilitation and mitigation measures no matter the extent of catchment urbanization.

Cities often are located on floodplains, commonly at stream junctions; therefore, engineering approaches that minimize flood effects and maintain water supplies have been ubiquitous. Thus, basin-scale flood control and water supply projects are common. Impoundments designed to capture seasonal runoff and deliver water during the dry season or to produce hydropower are often located hundreds of kilometers upstream of urban areas. Such reservoirs homogenize flow regimes, simplify geomorphology, modify stream temperatures, and disrupt processes that deliver sediment and large woody material. They also disturb fish migration timing and behavior via barriers and provide refuges for alien invasive species (Columbia Basin Fish and Wildlife Authority 1991; Ligon et al. 1995; Williams et al. 1996). Frequently, river and stream banks both far from and within cities are channelized, rip-rapped, or leveed to speed water conveyance, limit channel movement, and aid navigation (Sedell and Froggatt 1984; Florsheim et al. 2008). Such changes can impair aquatic vertebrate and macroinvertebrate assemblages far from the impoundments and channel alterations (Poff et al. 1997).

Many current urbanization conditions are affected by historical land and water uses, particularly agriculture and channel alterations. Aboriginal humans altered natural flora and fauna through harvest, fire, and agriculture, and they also built canals and ditches that likely altered aquatic biota locally (Denevan 1992, 2011; Delcourt and Delcourt 2004). Intensive hydraulic engineering projects existed centuries ago in the Americas (Marsh 1976; Helfman 2007; Walter and Merritts 2008) and millennia ago in Europe (Quintela et al. 1987) and Asia (Temple 2007). Thus, the landscapes upon which many cities are built already had been transformed by prior land uses (Harding et al. 1998; Van Sickle et al. 2004; Brown et al. 2009). However, urbanization stresses stream ecosystems to a greater degree than most types of agriculture (Steedman 1988; Wang et al. 2000; Rawer-Jost et al. 2004; Trautwein et al. 2011; Ligeiro et al. 2013). In any case, cumulative effects of land cover changes, from natural vegetation to agriculture to urban, reduce the capabilities of streams to support their native biota (Stanfield and Kilgour 2006; Stanfield and Jackson 2011; Stanfield 2012).

Since the industrial revolution, effects of urbanization accelerated, intensified, and became much more extensive (Petts 1989). Many urban streams now occur only within underground pipes or concrete canals. Urban rivers are typically channelized, rip-rapped, and leveed; littoral zones of residential lakes now have shorelines converted to docks or retaining walls; and once-dense riparian forests are converted to park-like savanna. Navigable estuaries are regularly dredged, with shoreline wetlands converted to wharfs, seawalls, and commercial enterprises. For many urban dwellers these highly altered waterscapes form their images of a typical stream, river, lake, or estuary because they are founded on what they first experienced as youths or they are the only aquatic ecosystems they know (Pauly 1995; Figure 1). However, professional fisheries biologists, aquatic ecologists, and conservationists have different images and expectations for water bodies because of the many ecosystem services they provide (Costanza et al. 1997; Ervin et al. 2012). So what can we do about it? We offer a how-to approach based on identifying root causes and their scale.

REHABILITATING EFFECTS OF EXISTING URBAN AREAS ON AQUATIC ECOSYSTEMS

In this section, we first discuss the general goals of rehabilitating aquatic ecosystems and the limitations of doing so. These limitations include the many existing physical and chemical constraints resulting from urban infrastructure, the complex interwoven types of urban pressures, and the site-scale versus catchment- or basin-scale approaches for rehabilitation. We then discuss four major rehabilitation approaches: reestablishing natural land cover, wastewater and stormwater management, recovering hydrological connectivity and geomorphic complexity, and, finally, small-scale approaches such as bank stabilization (Table 1; IMST 2010).

Figure 1. Top: Amazon Creek, Eugene, Oregon; bottom: Townline Lake, Clare County, Michigan.

The Goal Is to Restore Processes, Not Specific Habitats

The typical objective of most rehabilitation projects is short-term physical habitat improvement. However, the primary goal of restoration is not to jump in and create a habitat but to regain historical ecological structure by naturalizing ecosystem processes that support stable flow regimes, instream habitat connectivity, riparian vegetation, and water quality (Roni et al. 2002; Beechie et al. 2008). An additional goal is to make waters safe for body contact as prescribed by the Clean Water Act in the United States (U.S.C. 33 § 1251) or the Water Framework Directive in the European Union (European Commission 2000).

Of course, in most urban areas, natural processes are highly constrained by infrastructure (Carpenter et al. 2003; Booth 2005; Bernhardt and Palmer 2007), pollution sources (Paul and Meyer 2001), and substantial geomorphic alterations (Jennings et al. 1999, 2003; Brown et al. 2005; Walsh et al. 2005; Chin 2006; T. B. Francis and Schindler 2006; Kaye et al. 2006; R. A. Francis 2012). Consequently, aquatic ecosystems in urban areas cannot be restored to completely unimpaired conditions, but they can be rehabilitated to support desirable biota and water quality (National Research Council 1996; Booth 2005;

Table 1. Common site-scale rehabilitation techniques applied in urban areas.

Bank stabilization
Erosion control focused on stream banks and shorelines
Rip-rap, geotextiles, retaining walls, sea walls
Planting riparian areas and shorelines with native woody plants or grasses
Removal of alien invasive riparian plants
Hydrological connectivity
Improved fish passage at dams
Daylighting of piped streams
Dam and culvert removal and retrofitting
Rip-rap, retaining wall, and seawall removal
Levee and dike breaching and setbacks
Meander and wetland creation
Off-channel habitat and floodplain reconnection
Decreasing the amount of impervious surfaces
Hydromorphological complexity
Placement of large wood, gabions, boulders, or gravel in stream channels
Placement of large wood and brush in lakes and estuaries
Aquatic macrophyte reestablishment in lakes and estuaries
Wastewater and storm water management
Wastewater (industrial, institutional, and domestic) collection and treatment
Storm water collection, separation, and treatment
Erosion control focused on uplands
Reducing the amount of impervious surfaces
Increasing evapotranspiration and infiltration of stormwater
Reestablishing wetlands and riparian vegetation
Installing green roofs, temporary ponds, bioswales, and rain gardens

Simenstad et al. 2005; Roni et al. 2008; Coles et al. 2012). The key is to understand at what scale problems are occurring and then apply a correct prescription that matches the scale of the problem.

Storm water must be controlled at its source (i.e., the catchment), which involves protections via land-use planning and regulation rather than attempts to rehabilitate degraded channels

Know Your Scale

Urbanization alters the biota via multiple pathways operating simultaneously at multiple scales (Figure 2). For example, the presence of a city on a river may result in a local physical or chemical barrier to fish migration that also alters fish populations far from those barriers (e.g., Cooke et al. 2004; Regier et al. 2013). Conversely, well-meaning mitigation projects are implemented at the site or reach scale in streams, lakes, and rivers, when many of the limiting factors are occurring at the watershed scale (e.g., Fausch et al. 2002; Roni et al. 2002; Scott et al. 2002; Strayer et al. 2003; Wang et al. 2003, 2011; Moerke and Lamberti 2006; Beechie et al. 2010; Regier et al. 2013). This is not to say that local projects are meaningless because they can have cumulative effects, especially when it comes to watershed rehabilitation or managing stormwater (Stanfield 2012).

Typically, however, rehabilitation is planned and implemented at the site (10s to 100s of meters) or segment (1,000s of meters to kilometers) scale. Stanfield (2012) suggested that assessing multiple sites along a segment can guide when and where local rehabilitation may be effective. However, it is almost always more effective to perform rehabilitation at watershed or basin scales, with a focus on recovering natural flow regimes (e.g., Frissell and Nawa 1992; Muhar 1996; Poff et al. 1997; Booth 2005; Wohl 2005; Bernhardt and Palmer 2007; Jansson et al. 2007). Therefore, the priority actions for urban rehabilitation are to (1) protect existing upstream high-quality catchments and habitats and (2) reestablish ecosystem processes and connectivity in the altered places (especially water quality and hydrological regime), before attempting to rehabilitate specific sites lower in the watershed (National Research Council 1992, 1996; Booth et al. 2004; Booth 2005; Roni et al. 2002, 2008; Bernhardt and Palmer 2007; Beechie et al. 2008). These are also precepts proposed by McHarg (1969) and Poff et al. (1997), which are similar to recommendations by Noss (2000) for maintaining ecological integrity at regional scales. Of course, resource managers must recognize that lag times for responses may range from 1 to 100 years or longer (Roni et al. 2002, 2008; Bernhardt and Palmer 2007; Beechie et al. 2008), and results may not be evident immediately. In the following five subsections we summarize the major rehabilitation techniques and their known limitations (Table 1).

First: Rehabilitate the Watershed

Watershed rehabilitation involves two distinct issues: management of natural land cover and managing stormwater entering via rapid runoff from impervious surfaces.

Natural Land Cover

In forested ecosystems, watersheds that have experienced timber harvest or conversion to agriculture have generally higher bedloads, embeddedness, sediment loads, and less stable flows (Sutherland et al. 2002). We note that this is the natural condition for streams in dryer ecosystems (Dodds et al. 2004), but most resource managers in temperate regions would likely view achieving a high percentage of native vegetative cover within a watershed as beneficial. However, achieving that goal is challenging from multiple perspectives.

First, watersheds vary in size and complexity and span multiple social, economic, and political boundaries with different human densities, cultural values, and land uses. This makes coordination difficult and regulatory approaches problematic. The solution is often achieved through independent watershed councils that promote stewardship and coordination (e.g., Huron River Watershed Council 2013), but rehabilitating natural land cover requires participation by not only public lands managers but in some cases thousands of private landowners.

A second issue is that it is very difficult to relate specific management actions to outcomes. Most watershed rehabilitation

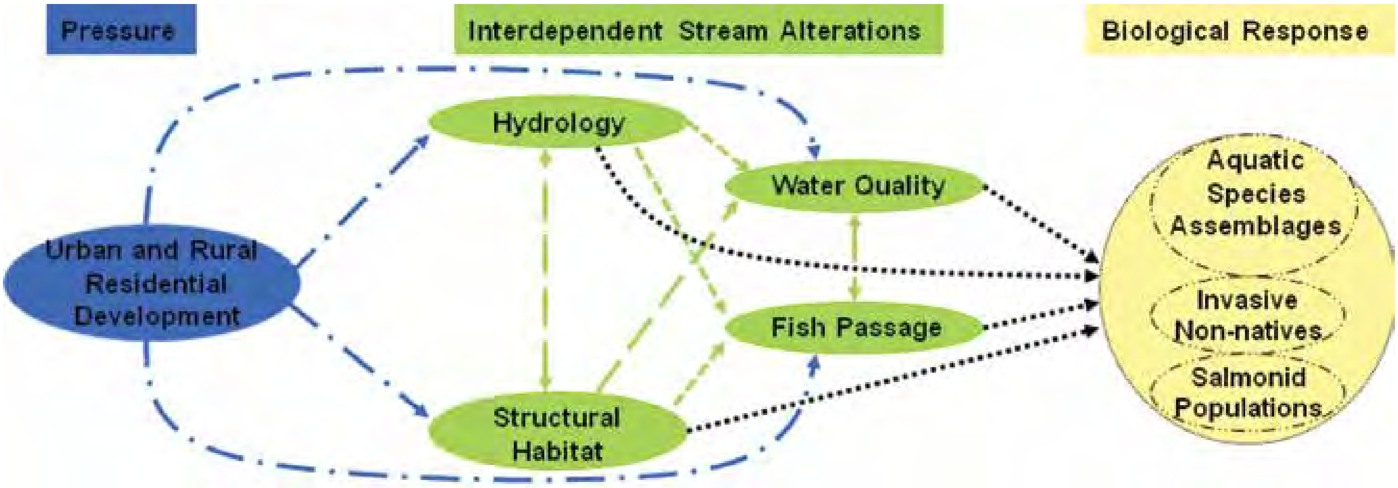

Figure 2. Interrelationships between urbanization pressures, interdependent stream alterations, and biological responses (IMST 2010).

efforts focus on encouraging riparian rehabilitation or best management practices that minimize agricultural runoff or erosion, the former because benefits are disproportionately large for the land area conserved (Quinn et al. 2001) and the latter because conversion of land to less-developed land covers is impractical (Allan 2004). However, the relationship between agricultural land cover and stream conditions is best described as highly variable with nonlinear relationships occurring at multiple scales. Some have reported that agricultural land use seems to have few effects on streams until about 30% to 50% of the watershed is farmed (e.g., Allan 2004), whereas Wang et al. (1997) reported high fish index of biotic integrity scores at sites with 80% agriculture. However, Trautman (1957) noted the demise of sensitive Ohio fishes in watersheds that experienced any loss of forest cover, and Gammon (2005) described how the Wabash River and its fish assemblages were altered soon after the land was cleared for farming. Apparently, other factors are at play, including what one uses as reference conditions and indicators.

So what are resource managers to do? It may be best to focus on riparian rehabilitation because that habitat has the most well-documented effects on stream condition (Naiman and Decamps 1997), and it also confers local habitat benefits at the reach scale (Brewer 2013). However, we note three caveats: (1) riparian rehabilitation can take many forms, depending on local physiographic conditions (a.k.a. one size fits none; Allan 2004); (2) in many watersheds extensive impervious surface coverage can override riparian services (Coles et al. 2012); and (3) extensive pipe networks can bypass riparian zones (Brewer 2013).

Storm Water

Storm water management is critical to small urban streams because runoff effects are especially severe. Some studies suggest that beyond 5%–15% urbanization diversity declines rapidly (Paul and Meyer 2001) because of the presence of impervious surfaces that result in rapid runoff (flashiness) that affects bank stability, hydrological connectivity, and hydromorphological complexity. To be effective, storm water must be controlled at its source (i.e., the catchment), which involves protections via land-use planning and regulation rather than attempts to rehabilitate degraded channels (Cairns 1989; Booth et al. 2004). Although a serious problem, there are a variety of prescriptions available.

The key to storm water management is to break the direct connection between the impervious surface and the stream (Cairns and Palmer 1995). There are a variety of available techniques: reconnecting stream channels to their floodplains, wetland and mini-natural area creation, reestablishing riparian vegetation, reducing the amount of impervious surfaces, and installation of green roofs, temporary ponds, bioswales, and rain gardens (Booth et al. 2004; Brand and Snodgrass 2010; IMST 2010; Schaeffer et al. 2012; City of Portland 2012a; Yeakley et al., 2014). These techniques function by increasing evapotranspiration and infiltration to the groundwater while reducing the volume of water routed directly into streams. Implementation of such green infrastructure also sequesters pollutants that might be flushed directly in high concentrations; however, Pataki et al. (2011) reported that bioswales may be nutrient sources depending on their management.

Storm water management has the added benefit of serving as aquatic habitat. Brand and Snodgrass (2010) determined that storm water retention ponds supported more amphibian breeding and rearing than natural wetlands, which were intermittently wet. Schaeffer et al. (2012) reported that a carefully designed and managed storm water retention pond provided habitat for 9 years for three regionally rare fish species that require clear water and dense aquatic macrophytes.

Second: Further Improve Wastewater Treatment

There is ample evidence that wastewater treatment benefits stream assemblages. In most developed nations, sewage and industrial effluent treatment have become commonplace, reducing waterborne diseases, improving water quality, providing opportunities for water-based recreation, and rehabilitating aquatic biological assemblages. Gammon (1976) and Hughes and Gammon (1987), respectively, reported only minor effects on fish assemblages exposed to treated urban wastewaters along 340 km of the Wabash River, Indiana, and 280 km of the Willamette River, Oregon—although both systems also endured agricultural pollution and channel modification. Weinbauer et al. (1980) found significantly improved water quality, fisheries, and aquatic biota in a 112-km reach of the Wisconsin River, Wisconsin, following treatment of paper and pulp mill effluents. Yoder et al. (2005) reported substantial improvement in Ohio fish assemblages following 20 years of increasingly improved urban sewage treatment. Mulvey et al. (2009) found that the major stressors on stream biotic assemblages in the Willamette Basin, Oregon, were excess temperature, riparian disturbance, and streambed instability, rather than urban sewage.

Although wastewater treatment is effective, we note that it is not universal and many rivers in developing nations suffer from severe pollution. Massoud et al. (2009) concluded that central wastewater treatment options in developing nations were inadequate because of infrastructure expense (especially collection costs); they suggested that decentralized strategies would be far more effective. However, Paulo Pompeu (Departmento de Biologia, Universidade Federal de Lavras, Lavras, Minas Gerais, Brazil, unpublished data) has found that secondary treatment of 70% of the sewage of the Belo Horizonte Metropolitan Region resulted in substantial recovery of the fish assemblage of the Rio das Velhas.

Even though most wastewater in developed nations is treated, two major problems remain. First, storm water flows (containing nutrients and toxins) can rapidly overwhelm treatment facilities, because in many cases storm water and wastewater systems are combined, and untreated water is released during storm events (Field and Struzenski 1972). Because flow separation is problematic and expensive, wet weather retrofits are often applied (Szabo et al. 2005). Second, treated wastewaters deliver untreated personal care products, pharmaceuticals, hormones, fire retardants, plasticizers, property maintenance chemicals, nanoparticles, heavy metals, solvents, and organochlorines (Dunham, 2014; Foster et al., 2014). Up to 200 of these largely unregulated and unmonitored emerging contaminants (many of which are endocrine disruptors) are released by wastewater treatment plants and in storm waters (Ritter et al. 2002). In addition, streams and lakes receiving treated wastewaters still experience increased nutrient loadings, especially where wastewaters comprise much of the flow. In any case, urban managers can become familiar with wastewater systems in their jurisdictions, implement techniques for removing untreated chemicals from the waste stream by regulation and treatment, and know how those systems are operated and their limitations.

Third: Rehabilitate Longitudinal, Lateral, and Vertical Hydrological Connectivity

Improvements in hydrological connectivity result in increased movement of water, sediment, wood, and biota longitudinally, horizontally, and vertically (Pess et al. 2005a). Dam and culvert removal—or retrofitting—improves longitudinal connectivity and fish passage and downstream movement of sediment and large wood (Pess et al. 2005b; Price et al. 2010). Most studies we reviewed have been in forested areas where fish showed rapid positive responses to such changes when those improvements were properly designed; that is, culverts were appropriate for all life stages and most flows (Beechie et al. 2008; Roni et al. 2008). However, urban dam removals and modifications also improve fish passage (Blough et al. 2004).

Improved horizontal connectivity rehabilitates floodplains through levee breaching or setbacks, rip-rap removal, meander creation, and off-channel habitat reconnection (Pess et al. 2005a). Most studies we examined have involved rural and forested streams, and the majority indicated improved physical or biological conditions (Beechie et al. 2008; Roni et al. 2008)—and some studies have found positive effects in urban environments. Levell and Chang (2008) reported physical improvements 2 years after channel restructuring relative to an urban site but found less channel and substrate stability than in a nonurban reference site. Kaushal et al. (2008) reported that a rehabilitated reach of a Baltimore, Maryland, stream had significantly lower nitrate concentrations than an unrehabilitated reach of the same stream. Daylighting (reexposing piped streams to allow flooding and riparian vegetation) has occurred in several U.S. streams, but too few have been monitored to arrive at conclusions concerning ecological effects (Bucholz and Younos 2007). The greatest challenge is that urban infrastructure may constrain such measures (Brown et al. 2009; IMST 2010), but we believe that opportunities exist in many cities that have abandoned or neglected waterfronts and riparian zones. Those areas might be rehabilitated as public green spaces within the historic floodplain (City of Portland 2012b; Yeakley et al., in press).

Vertical connectivity is the exchange between groundwater and surface water in aquatic systems, but techniques for rehabilitating vertical connectivity rarely have been evaluated (Boulton 2007). Kaushal et al. (2008) reported that groundwater in a rehabilitated Baltimore, Maryland, stream reach had significantly lower nitrate concentrations and higher denitrification rates than in an unrehabilitated reach of the same stream. Denitrification was significantly higher in reaches where rehabilitation promoted overland flooding and seepage to groundwater versus seepage in rehabilitated reaches that were unconnected to their floodplains. Groffman et al. (2003) also found that denitrification potential decreased with channel incision and lowered water tables in urban riparian zones. In addition, increased vertical and horizontal connectivity with the water body, as opposed to stream incision or lake drawdown, is necessary for rehabilitating and sustaining riparian woody vegetation versus upland vegetation (Scott et al. 1999; Groffman et al. 2003; Kaufmann et al., in press). We note that among the major rehabilitation techniques, improved hydrological connectivity frequently shows the most immediate responses in fish passage and water quality improvement.

Fourth: Improve Hydromorphological Complexity

Common hydromorphological rehabilitation techniques include placement of large wood, boulders, or gravel into stream channels. In forest streams, those alterations usually increased physical habitat complexity, but their biological effects are uncertain because of insufficient monitoring, method and stream variability, and study design flaws that make increased fish production indistinct from increased fish concentration (e.g., Roni et al. 2005, 2006, 2008; Thompson 2006; Stewart et al. 2009; Whiteway et al. 2010). In addition, urban streams experience more flashiness and poorer water quality than forest streams, which together may override hydromorphological complexity (Larson et al. 2001; Booth 2005; Brewer 2013). Most studies reviewed suggest that local rehabilitation actions have little effect. Larson et al. (2001) reported that adding large wood did not improve benthic macroinvertebrate assemblages in Washington urban streams. Gravel augmentation in a highly disturbed California river increased Chinook Salmon (*Oncorhynchus tshawytscha*) spawning activity (Merz and Setka 2004) and egg-to-alevin survival (Merz et al. 2004) but not macroinvertebrate densities (Merz and Ochikubo Chan 2005). Violin et al. (2011) found no differences between macroinvertebrate assemblages and instream physical habitat of rehabilitated versus degraded urban streams in the North Carolina Piedmont. In summary, restoration of local structural complexity is unlikely to provide benefits and unlikely to persist if flow modifications and hydrological connectivity are not also addressed (Frissell and Nawa 1992; DeGasperi et al. 2009). The rare exceptions may be cases where a stream is so degraded that all within-channel habitat is lacking, but we note that those streams are likely experiencing large-scale problems as well.

Fifth: Last and Least, Stabilize Banks

Several types of erosion control techniques (rip-rap, geotextiles, gabions, retaining walls, sea walls) are employed more to protect economically valuable infrastructure than to rehabilitate natural processes of channel and shoreline erosion and migration. Such techniques transmit the energy of moving water downstream or down current to other shorelines and river banks. Because these bank hardening techniques are directed toward infrastructure protection and typically impair biotic condition and ecological processes (Sedell and Beschta 1991), we do not emphasize them in this review.

Riparian vegetation stabilizes banks and improves conditions for sensitive fish taxa in lakes, streams, and rivers. Vegetation plantings can decrease bank erosion and increase shredder macroinvertebrate diversity (Sudduth and Meyer 2006) while decreasing solar inputs, but the magnitudes of these effects on urban fish assemblages are uncertain. In lakes, Kaufmann et al. (in press) reported that increased littoral and riparian vegetation cover complexity was associated with increased richness of eutrophication-intolerant fish species (Figure 3A) and decreased richness of eutrophication-tolerant fish species (Figure 3B). Groffman et al. (2003) and Roni et al. (2008) emphasized that riparian vegetation is more likely to persist if flow modifications and hydrological connectivity are also addressed; however, additional studies are needed to document those assumptions. In contrast, rip-rap has an opposite effect; however, more controlled and multisite studies are needed. Schmetterling et al. (2001) reported that rip-rap reduced the development of undercut banks, gravel deposits, and riparian vegetation, which provide fish cover, and Kondolf et al. (2006) indicated that rip-rap increased downstream erosion in rivers.

In summary, urban water bodies cannot be restored to predisturbance conditions, but they can be improved to support desirable biota and water quality. Rehabilitation of urban aquatic ecosystems is challenging because of multiple and interacting biophysical urban constraints, as well as continuous inputs from and interactions with urban residents. Multiple rehabilitation measures taken at the catchment scale are most effective if they focus on reestablishing ecosystem processes and rehabilitating natural vegetation, hydrological regimes, and water quality—before attempting to rehabilitate degraded instream hydromorphology at the site scale. Resource managers skilled at diagnosing the scale at which problems are occurring will be able to apply the best prescription. And in urban sites, fisheries professionals working closely with urban planners and wastewater engineers will be able to ameliorate effects of storm water.

Our review focused on rehabilitation of urban streams that had been damaged previously. Urbanization is an ongoing phenomenon, with a progressively larger proportion of humans moving into urban areas that are likely to expand. Thus, more streams are likely to become urbanized in the future. Ideally, there would be a way to prevent damage inexpensively rather than repair extensive damage expensively. We will explore that topic in Hughes et al. (2014) and point to what still needs to be learned about urban streams to make mitigation more effective, including climate change and sociological issues.

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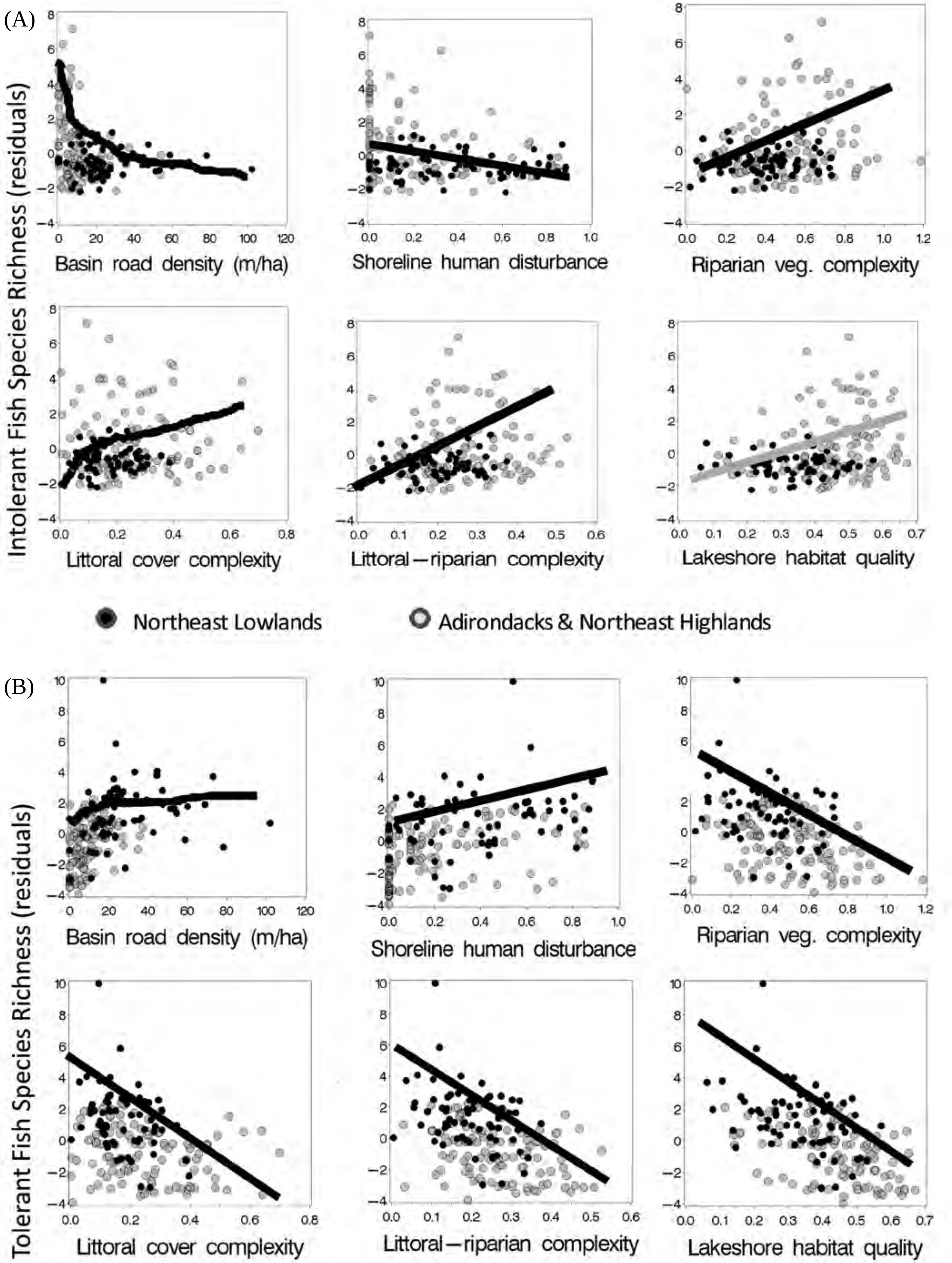

Figure 3. Responses of intolerant fish (A) and tolerant fish (B) to lake littoral and riparian condition (adapted from Kaufmann et al., in press). Richness regression residuals were used to calibrate for the effect of lake area on species richness. Lines are 95th percentile quantile regressions.

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DRAFT WORK PLAN
"EXPERT INTERPRETATION OF THE BIOLOGICAL CONDITION GRADIENT IN CALIFORNIA WADEABLE STREAMS"
NOVEMBER 2016 UPDATE

Martha Sutula, Eric Stein, Raphael Mazor, Susanna Theroux (SCCWRP)
Michael Paul, Benjamin Jessop, Jeroen Gerritsen (Tetra Tech Inc.)

INTRODUCTION AND GOAL OF DOCUMENT

The California State Water Resources Control Board (State Water Board) is developing a combined biostimulatory substances and biointegrity policy and a program of implementation for the state's surface waters (SWRCB 2014). For wadeable streams, the State Water Board staff proposes to establish a narrative biostiumulatory objective applicable to all water body types and numeric guidance specifically for wadeable streams. A science plan has been developed to support the Water Board staff to create numeric guidance for wadeable streams (Sutula et al. 2015). Element 1.2 of that plan describes work to "Determine the numeric range of stream nutrient and response indicators that correspond to varying levels of beneficial use support."

One of the three approaches to accomplish Element 1.2, identified in the Sutula et al. (2015) Science Plan, is the development of a "Biological Condition Gradient" (BCG) model, with the intent to map that interpretation specifically onto wadeable stream bioassessment indices. The BCG, developed by biologists from across the United States, is a narrative conceptual model that describes changes to the ecological attributes of biological communities and ecosystems along a gradient of increasing anthropogenic stress (Figure 1, Appendix A and related information). Even in different geographic and climatological areas, a similar sequence of biological alterations occurs in aquatic ecosystems in response to increasing stress. In practice, this conceptual model can be made quantitative by first identifying the critical attributes of an aquatic community and then describing how the attributes change in response increasing anthropogenic stress. Experts score sites in ~ six bins of condition, from minimally disturbed "reference" condition to very low condition, using information on taxonomic composition of fauna (e.g. benthic macroinvertebrate) or flora (algae) and other information on natural environmental gradients. After scoring the sites, experts will be asked to reconcile their classification of sites to BCG bins and come to consensus on the ecological rationale used for this classification. The range of macroinvertebrate California Stream Condition Index (CSCI), the algal stream condition index (ASCI) scores, and other indicators of eutrophication (benthic chl-a, ash-free dry mass, algal percent cover) represented by each BCG bin will be summarized. These response indicator "BCG" bins will be mapped back to nutrient concentrations.

This document describes the objectives, proposed approach, key products and timeline for the development and application of the BCG model, based on benthic macroinvertebrates and algae for California wadeable streams.

Appendix (A) provides the list of BCG expert panelists with their biographies.

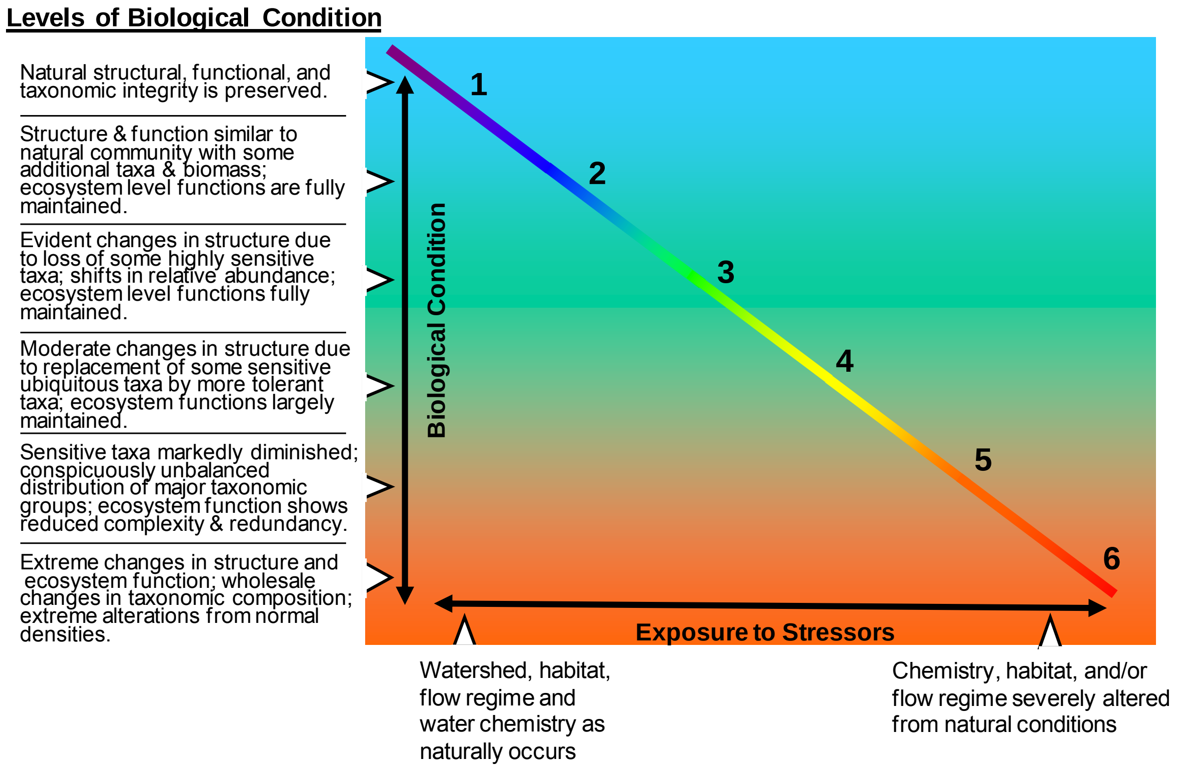

Figure 1. The Biological Condition gradient (BCG), modified from Davies and Jackson 2006. The BCG was developed to serve as a scientific framework to synthesize expert knowledge with empirical observations and develop testable hypotheses on the response of aquatic biota to increasing levels of stress. It is intended to help support more consistent interpretations of the response of aquatic biota to stressors and to clearly communicate this information to the public, and it is being evaluated and piloted in several regions and states.

Project Goal and Approach

The goal of the project to produce a BCG model for California wadeable stream fauna and flora that can be used to place sample sites in bins of ecological condition and can be used to relate algal and invertebrate assemblage metrics, organic matter accumulation, and nutrient gradients along these same bins.

Approach:

1. Conduct expert workshops to elicit from stream benthic macroinvertebrate and algal experts the categorization of a suite of selected sites along the biological condition gradient;
2. Get consensus from experts on the final BCG bin assignments for selected sites in California by stream class;
3. Describe BCG binned distributions in CSCI and ASCI scores;

4. Produce a report describing BCG expert interpretation, the range of BCG binned response indicators and how those BCG bins compare to ranges found by Fetscher et al. 2014 and reference distributions.

Approach and Detailed Task Description

The approach to develop and apply a BCG model consists of 6 tasks:

Task 1. Identify Experts
Task 2. Manage Data and Develop Supporting Information for Expert Scoring
Task 3. Develop the BCG Categorization Protocol and Supporting Information for Expert Scoring
Task 4: Develop BCG Model, Based on Expert Scoring and Reconciliation
Task 5: Crosswalk BCG Condition Categories to Ranges of CSCI and ASCI scores
Task 6: Produce a Report Summarizing BCG Model and Application

Task 1. Identify Experts

The purpose of this task is to identify 15 stream ecologists that represent expertise in using benthic macroinvertebrate (BMI) and algal community data to describe stream condition. For BMI, 10 experts will recruited represent a range of expertise needed to apply required to represent 9 California wadeable stream ecoregions. For algae, 5 experts will be recruited, as current taxonomic expertise representing California ecoregions is not available. Experts will be drawn from academic institutions, consultants, or agency staff. Experts can reside inside or outside of California, but should have expertise in California ecoregions.

Task 1 Deliverables: 1) *Draft list of experts (Appendix B), and 2) Final list of experts*

Task 2: Manage Data and Update Tolerance Values for Macroinvertebrate and Algal Functional Traits

The purpose of this task is to: 1) aggregate and manage stream bioassessment data for use throughout the project, 2) conduct exploratory analyses and update the database of tolerance values for BMI and algal functional traits.

2a. Update existing stream bioassessment databases.

Existing bioassessment databases will be updated to append data, already compiled, that have complete stressor and response information and that are readily available.

2b. Conduct stress-response exploratory analyses and define attributes and update trait tolerance values based on California taxa

The conceptual BCG model relies on a set of attributes, and some sort of expected values for the attributes. Attributes are in the broad categories of taxonomic attributes, organism condition, functional attributes, and spatial attributes. Stream biological monitoring generally obtains information on the taxonomic attributes (species richness, identity of taxa, abundance, and relative abundance) and less frequently on the other attribute groups. The primary attributes available are on sensitivity and tolerance of taxa, and these have been widely reported in the bioassessment literature. In spite of widely published tolerance values (e.g., Merritt et al. 2008 [4th edition], many published tolerance values tend to be earlier work from different areas of the country, that are propagated through successive compilations. They may or may not apply to California and the species and varieties that occur in California. Data analyses will be conducted to support the following objectives and to update the database of tolerance values for functional traits, as needed.

- Confirm data density for taxa in each ecoregion,
- Map taxon distributions,
- Compile existing associations between stressors and established bioassessment metrics and compile information on available traits and/or functional taxon relationships.

2c: Prepare Data for Expert Scoring

The purpose of this task is to select sites that represent designated classes of interest and that represent the full range of stressors (nutrients, response indicators) values to which the BCG will be applied. The type and quantity of data will be determined by Task 2a and b and the final numbers of experts, but will include data on sites representing a gradient of conditions across multiple ecoregions. At a minimum, it will include taxonomic data, sample metadata, ecoregional and classification information, and general information on environmental gradients. This analysis is essentially a synthesis of analyses from Task 2a and b, updated based on Task 3 feedback from the experts. The sites should span the range of disturbance identified in Task 2a, from least disturbed that can be found (sensu Stoddard et al. 2006), to the most disturbed and altered, again within each recognized stream class. Sites can be assigned to 5 or 6 bins of disturbance. Extent of disturbance is used to help select sites given to the panel, but is not communicated to the panelists.

Experts will be given a set of ~100 sites from each identified class of streams, relevant to the assemblage (algae or benthic macroinvertebrates), to score independently, without data on stressors. The timing of this subtask is such that at the initial workshop (Task 3), the data will be ready except for the final classification. As soon as the classification is agreed to and finalized by the experts, selection of sites can be made and the data will be distributed to the experts at the end of the workshop.

Task 2 Deliverables:

Updated database for use throughout project,
Geographic distributions, stress-response associations, traits/functional associations
Selected sites and associated data for use by experts

Task 3 Develop the BCG Categorization Protocol and Supporting Information for Expert Scoring

The purpose of this task is to assemble experts, introduce the protocol for categorizing sites, agree on how to account for natural gradients, and develop supporting databases of taxonomic attributes, tolerance values and/or functional traits.

Task 3a. Introduce Protocol for Classifying Sites

A general protocol exists for the development and calibration of quantitative BCG model. Two webinars and a short (2-day) workshop to introduce new experts to the concept and process lays a foundation in advance of the actual classification and scoring workshop. This can be conducted as combination of webinars and/or face-to-face workshop, depending on the final mix of novice vs experienced panelists; an in-person workshop may be more effective if the experts include a fair number of novices to the BCG. The webinars and introductory workshop will have the following objectives:

- Introduction to BCG in context of WQ management,
- Conduct a trial run of classifying a handful of sites to familiarize participants,
- Get consensus on what site information will be given to experts (e.g. raw taxonomic data, calculated metrics and reference expectation for those metrics, environmental gradients).
- Detailed work with taxonomic lists: experts begin to rate/rank taxa as indicators of stress, based on stress-response associations, and as indicators of BCG attributes. This step can continue as homework for finalization at 2nd workshop

The first part of the meeting will be a relatively thorough explanation of the BCG with emphasis on the conceptual model as described in Davies and Jackson (2006). Two key handouts that will be useful to participants throughout the process are brief descriptions of each level of the BCG, and brief descriptions of attributes of structure, function, and other components, and how they respond to anthropogenic stress (Table 1, Table 2).

3b. Conduct a Trial run and Agree on Scoring Protocol

The expert panel will be given data from 3 – 5 sites, generally spanning the range of stresses found in California. Participants will be given no information on land use, physical, or chemical stress in the sites, and they will be asked to assign each site to one of the 6 levels of the BCG and rank sites, on their own. After they have assigned the sites, the group will reconvene to tally and discuss the results. This exercise is a preview for the homework that will be assigned to the panel. The panelists will then discuss how they rated sites and agree upon a protocol for all to follow when they are rating the sites.

Task 3 Deliverables:

Introductory Webinars and/or Expert Workshop on BCG
Agreement from experts on BCG attributes

Task 4: Develop a BCG of California Wadeable Streams from Expert Scoring and Reconciliation

The purpose of this task is to have experts develop consensus on scoring or ranking sites, and to elicit rules from the experts that they use in their scoring. Experts will score the sites provided in Task 3, independently. A second workshop of two- to three-days will bring the experts back together to reconcile their scores and ranks and to identify the rules that they can agree on. The goal of this workshop is to reconcile the scoring to develop consensus on a set of rules that are transparent, and levels of condition that are ecologically interpretable and meaningful, in order to translate these BCG bins to ranges of scores for the CSCI, algal SCI, and organic matter indicators (benthic chl-a, AFDM, and percent cover).

Deliverables:

Expert Scoring Workshop on BCG and Follow up Webinars

Presentation summarizing consensus on scoring of sites to yield condition classification, and elicitation of rules

Task 5: Crosswalk BCG Condition Categories to Ranges of CSCI and ASCI scores

The utility of the BCG model for to support policy decisions lies in relating each of the BCG categories to ranges in CSCI and ASCI (when available). Furthermore, thresholds using other approaches than the BCG already exist. Fetscher et al. (2014) identified breakpoints in relationships between CSCI index scores and stressor gradients (algal abundance and nutrients). These breakpoints correspond to thresholds in stressor gradients where adverse effects on biological response metrics occur. It is useful to understand the how Fetscher et al. (2014) and reference derived ranges relate to those derived from BCG categories.

The purpose of this task is to derive BCG referenced ranges in the CSCI, algal SCI and 2) compare those ranges to Fetscher et al. (2014) thresholds and reference levels.

Deliverables:

Presentation summarizing the relationship of BCG tiers to intermediate indicators and stressor gradients of interest

Task 6: Produce a Report Summarizing BCG Model and Application

The purpose of this task is to produce a draft and final report summarizing BCG model development and applications for identifying ranges of concentrations of intermediate response and stressors indicators of interest, relative to Fetscher et al. (2014).

Deliverables:

Draft Report

Final Report

Schedule of Deliverables

Task No.	Description of Deliverable	Estimated Schedule for Completion
Task 1	**Identify Experts**	
1.1	List of algal and benthic macroinvertebrate experts (Appendix B)	July 31, 2016
Task 2	**Manage Data and Prepare for Use By Experts**	
2.1	Updated database for use throughout project	September 30, 2016
2.2	Presentation geographic distributions, stress-response associations, traits/functional associations	September 30, 2016
2.3	Prepare selected sites and associated data for use by experts	October 31, 2016
Task 3	**Develop the BCG categorization protocol and supporting information for expert scoring**	
3.1	Presentations used in introductory webinars and/or expert workshop on BCG with preliminary assignment of species and other BCG attributes	December 31, 2016
Task 4	**Develop a BCG of California Wadeable Streams from Expert Scoring and Reconciliation**	
4.1	Presentations from Expert Scoring Workshop on BCG and follow up webinars (as needed)	July 31, 2017
Task 5	**Crosswalk BCG Condition Categories to Ranges of CSCI and ASCI scores**	
5.1	Presentation summarizing the relationship of BCG tiers to CSCI and ASCI	July 31, 2017
Task 6	**Report Summarizing BCG Model Development and Application**	
6.1	Draft report	September 30, 2017
6.2	Final report	November 30, 2017

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Appendix A.

Table A1. BCG Attributes and Description

BCG Attributes	Description
I. Historically documented, sensitive, long-lived or regionally endemic taxa:	Refers to taxa known to have been supported in a waterbody or region prior to enactment of the Clean Water Act, according to historical records compiled by state or federal agencies or published scientific literature. Sensitive or regionally endemic taxa have restricted, geographically isolated distribution patterns (occurring only in a locale as opposed to a region), often due to unique life history requirements. They may be long-lived, late maturing, low fecundity, limited mobility, or require a mutualist relation with other species. May be among listed endangered/threatened or special concern species. Predictability of occurrence is often low, therefore, requiring documented observation. Recorded occurrence may be highly dependent on sample methods, site selection and level of effort.
II. Highly Sensitive Taxa:	Refers to taxa that naturally occur in low numbers relative to total population density but may make up large relative proportion of richness. They may be ubiquitous in occurrence or may be restricted to certain micro-habitats, but because of low density, recorded occurrence is dependent on sample effort. Often stenothermic (having a narrow range of thermal tolerance) or cold-water obligates; they are commonly k-strategists (populations maintained at a fairly constant level; slower development; longer life-span). They may have specialized food resource needs or feeding strategies and are generally intolerant to significant alteration of the physical or chemical environment; is often the first taxa observed to be lost from a community.
III. Intermediate Sensitive Taxa, (or Sensitive and Common Taxa):	Refers to taxa that are ordinarily common and abundant in natural communities when conventional sample methods are used. They often have a broader range of thermal tolerance than Sensitive- Rare taxa. These are taxa that comprise a substantial portion of natural communities, and that often exhibit negative response (loss of population, richness) at mild pollution loads or habitat alteration.
IV. Taxa of Intermediate Tolerance:	Refers to taxa that make up a substantial portion of natural communities; may be r-strategists (early colonizers with rapid turn-over times; "boom/bust" population characteristics). They may be eurythermal (having a broad thermal tolerance range). May have generalist or facultative feeding strategies enabling utilization of relatively more diversified food types. Readily collected with conventional sample methods. May increase in number in waters with moderately increased organic resources and reduced competition but are intolerant of excessive pollution loads or habitat alteration.
V. Tolerant Taxa:	Taxa that make up a low proportion of natural communities. These taxa often are tolerant of a broader range of environmental conditions and are thus resistant to a variety of pollution or habitat induced stress. They may increase in number (sometimes greatly) in the absence of competition. Commonly r-strategists (early colonizers with rapid turn-over times; "boom/bust" population characteristics), able to capitalize when stress conditions occur. These are the last survivors in severely disturbed systems.
VI. Non-native or Intentionally Introduced Species	With respect to a particular ecosystem, any species that is not found in that ecosystem. Species introduced or spread from one region of the U.S. to another outside their normal range are non-native or non-indigenous, as are species introduced from other continents.
VII. Organism Condition (especially of	General indicators of organism health, such as deformities, anomalies, lesions, tumors, or excess parasitism are all external indicators of condition.

long-lived organisms)	
VIII. Ecosystem Function	Function includes trophic levels, production, respiration, total biomass and biomass in functional levels, P/R ratios, etc.
IX. Spatial and Temporal Extent of Detrimental Effects	The spatial extent of damage or degradation from a particular source.
X. Ecosystem Connectance	Natural connections and relation among ecosystem units, such as extent fragmentation, connections of riparian areas with the stream and floodplain, etc.

Description of the Biological Condition Gradient Levels

Although the BCG is continuous in concept, it has been divided into six levels to provide as much discrimination of different levels of condition as workgroup members deemed discernable, given current assessment methods and robust monitoring programs. It has been divided into six levels (as opposed to single pass-fail criteria) to foster both identification of consistent condition classes and management of the gradient of condition. Defining the levels between 3 and 5 was a challenge to the workgroup and entailed considerable discussion. The workgroup ultimately agreed some states and tribes may only be capable of discriminating 3-4, levels while others might be capable of discerning 6 levels based on characteristics of their database and monitoring program. However the workgroup agreed that the important role of the BCG model is to be a starting point for a state or tribe to think about how to use biological assessments and criteria to refine their designated aquatic life uses and to communicate more clearly about biological condition. There is no expectation that states and tribes must establish six levels of use classes. The ultimate number of the levels is a state or tribal determination.

Level 1: Natural or native condition.

Native structural, functional, and taxonomic integrity is preserved; ecosystem function is preserved within the range of natural variability.

Level 1 represents biological conditions as they existed (or still exist) in the absence of measurable effects of human disturbance. The Level 1 biological assemblages that occur in a given biogeophysical setting are the result of adaptive evolutionary processes and biogeography that selects in favor of survival of the observed species. For this reason, the expected Level 1 assemblage of a stream from the arid southwest will be very different from that of a stream in the northern temperate forest. The maintenance of native species populations and natural diversity of sensitive, long-lived species is essential for Levels 1 and 2. Non-native taxa are permissible in Level 1 only if they cause no displacement of native taxa, although the practical uncertainties of this provision are acknowledged. Attributes I and II (e.g., historically documented and sensitive taxa) assess the status of native taxa and thus should also identify threatened or endangered species when classifying a site or assessing its condition.

Level 2: Minimal changes in structure of the biotic community and minimal changes in ecosystem function.

Virtually all native taxa are maintained with some changes in biomass and/or abundance; ecosystem functions are fully maintained within the range of natural variability.

Level 2 represents the earliest changes in densities, species composition, and biomass that occur as a result of slight physical disturbances (such as increased temperature regime) or enrichment. There may be some reduction of a small fraction of highly sensitive or specialized taxa (Attribute II) or loss of some endemic or rare taxa. Level 2 can be characterized as the first change in condition from natural and it is most often manifested as slightly *increased* richness and density of taxa from Attributes III and IV, relative to Level 1 conditions.

Level 3: Evident changes in structure of the biotic community and minimal changes in ecosystem function.

Evident changes in structure due to loss of some rare native taxa; shifts in relative abundance of taxa but sensitive-ubiquitous taxa are common and abundant; ecosystem functions are fully maintained through redundant attributes of the system.

Level 3 represents readily observable changes that often occur in response to organic enrichment or increased temperature. The "evident" change in structure for Level 3 is interpreted to be perceptible and detectable decreases in sensitive-rare or highly sensitive taxa (Attribute II) and increases in sensitive-ubiquitous taxa or opportunist organisms (Attributes III and IV). Attribute IV taxa (intermediate tolerants) may increase in abundance as an opportunistic response to nutrient inputs.

Level 4: Moderate changes in structure of the biotic community with minimal changes in ecosystem function.

Moderate changes in structure due to replacement of some sensitive-ubiquitous taxa by more tolerant taxa, but reproducing populations of some sensitive taxa are maintained; overall balanced distribution of all expected major groups; ecosystem functions largely maintained through redundant attributes.

Level 5: Major changes in structure of the biotic community and moderate changes in ecosystem function.

Sensitive taxa are markedly diminished; conspicuously unbalanced distribution of major groups from those expected; organism condition shows signs of physiological stress; ecosystem function shows reduced complexity and redundancy; increased build-up or export of unused materials.

Changes in ecosystem function (as indicated by marked changes in food-web structure and guilds) are critical in distinguishing between Levels 4 and 5. This could include the loss of functionally important sensitive taxa and keystone taxa (Attribute I, II and III taxa) such that they are no longer important players in the system, though a few individuals may be present. Keystone taxa control species composition and trophic interactions, and are often, but not always, top predators. Tolerant non-native taxa (Attribute VI) dominate some assemblages and organism condition (Attribute VII) deteriorates. As an example, removal of keystone taxa by overfishing has greatly altered the structure and function of many coastal ocean ecosystems (Jackson et al. 2001).

Level 6: Severe changes in structure of the biotic community and major loss of ecosystem function.

Extreme changes in structure; wholesale changes in taxonomic composition; extreme alterations from normal densities and distributions; organism condition is often poor; ecosystem functions are severely altered.

Level 6 systems are taxonomically depauperate (low diversity and/or number of organisms) compared to the other levels. Extremely high or low densities of organisms caused by excessive organic enrichment or severe toxicity may characterize Level 6 systems.

IMPORTANT DEFINITIONS

Definitions of Terms used in the Biological Condition Gradient (Modified from Davies and Jackson 2006).

Historically Documented Taxa: refers to taxa known to have been supported in a waterbody or region prior to enactment of the Clean Water Act, according to historical records compiled by state or federal agencies or published scientific literature.

Invasive species – a species whose presence in the environment causes economic or environmental harm or harm to human health. Native species or non-native species may show invasive traits, although this is rare for native species and relatively common for non-native species. (Please note – this term is not currently included in the Biological Condition Gradient).[1]

Non-native or intentionally introduced species – with respect to a particular ecosystem, any species that is not found in that ecosystem. Species introduced or spread from one region of the U.S. to another outside their normal range are non-native or non-indigenous, as are species introduced from other continents.

Sensitive taxa: intolerant to a given anthropogenic stress; first species affected by the specific stressor to which they are "sensitive" and the last to recover following restoration.

Sensitive or regionally endemic taxa: taxa with restricted, geographically isolated distribution patterns (occurring only in a locale as opposed to a region), often due to unique life history requirements. May be long-lived, late maturing, low fecundity, limited mobility, or require mutualist relation with other species. May be among listed Endangered/Threatened or special concern species. Predictability of occurrence often low, therefore, requiring documented observation. Recorded occurrence may be highly dependent on sample methods, site selection and level of effort.

Highly Sensitive Taxa: taxa that naturally occur in low numbers relative to total population density but may make up large relative proportion of richness. May be ubiquitous in occurrence or may be restricted to certain micro-habitats, but because of low density, recorded occurrence is dependent on sample effort. Often stenothermic (having a narrow range of thermal tolerance) or cold-water obligates; commonly K-strategists (populations maintained at a fairly constant level; slower development; longer life-span). May have specialized food resource needs or feeding strategies. Generally intolerant to significant alteration of the physical or chemical environment; are often the first taxa observed to be lost from a community.

Intermediate Sensitive Taxa: ordinarily common and abundant in natural communities when conventional sample methods are used. Often having a broader range of thermal tolerance than Sensititve- Rare taxa. These are taxa that comprise a substantial portion of natural communities, and that often exhibit negative response (loss of population, richness) at mild pollution loads or habitat alteration.

Taxa of Intermediate Tolerance: taxa that comprise a substantial portion of natural communities; may be r-strategists (early colonizers with rapid turn-over times; "boom/bust population characteristics). May be eurythermal (having a broad thermal tolerance range). May have generalist or facultative feeding strategies enabling utilization of relatively more diversified food types. Readily collected with conventional sample methods. May increase in number in waters with moderately increased organic resources and reduced competition but are intolerant of excessive pollution loads or habitat alteration.

Tolerant Taxa: taxa that comprise a low proportion of natural communities. Taxa often are tolerant of a broader range of environmental conditions and are thus resistant to a variety of pollution or habitat induced stress. They may increase in number (sometimes greatly) in the absence of competition. Commonly r-strategists (early colonizers with rapid turn-over times; "boom/bust" population characteristics), able to capitalize when stress conditions occur. Last survivors.

attribute: measurable part or process of a biological system

ecosystem-level functions: processes performed by ecosystems, including, among other things, primary and secondary production; respiration; nutrient cycling; decomposition.

function: processes required for normal performance of a biological system (may be applied to any level of biological organization)

life-history requirements: environmental conditions necessary for completing life cycles (including, among other things, reproduction, growth, maturation, migration, dispersal)

maintenance of populations: sustained population persistence; associated with locally successful reproduction and growth

native: an original or indigenous inhabitant of a region; naturally present

non-detrimental effect : do not displace native taxa

refugia: accessible microhabitats or regions within a stream reach or watershed where adequate conditions for organism survival are maintained during circumstances that threaten survival, eg drought, flood, temperature extremes, increased chemical stressors, habitat disturbance, etc

spatial and temporal ecosystem connectance: access or linkage (in space/time) to materials, locations, and conditions required for maintenance of interacting populations of aquatic life; the opposite of fragmentation; necessary for metapopulation maintenance and natural flows of energy and nutrients across ecosystem boundaries

structure: taxonomic and quantitative attributes of an assemblage or community, including species richness and relative abundance

Appendix B.

List of BCG Panel Experts and Biographies, By Expertise

Algal Taxonomy and Ecology

Donald Charles, Ph.D., Leader, Phycology Section, The Academy of Natural Sciences' Patrick Center for Environmental Research (http://diatom.ansp.org/).

Dr. Charles is leader (since 1992) of the Phycology Section in the Patrick Center for Environmental Research (PCER) and a professor in Drexel's Department of Biodiversity, Earth and Environmental Science. He was Ruth Patrick Chair in Environmental Science, ANSP (2005 – 2010) and served a year each as Director and Acting Director of the PCER. He obtained a B.Sc. from The SUNY College of Environmental Science and Forestry (1971) and from Syracuse University (1971), his M.Sc. from Cornell University (1974), and his Ph.D. from Indiana University (1982). He worked as Aquatic Ecologist for New York State's Adirondack Park Agency (1973-1977), held research positions at Indiana University (1982-1986), and was a university-cooperator Limnologist at the U.S EPA's Environmental Research Laboratory in Corvallis, OR (1987-1991). He has authored / co-authored more than 60 scientific articles and over 65 reports. Research interests include ecology of diatoms and their use as environmental indicators in assessment of river water quality and in paleolimnolgical studies; basic and applied aspects of nutrient enrichment, acidification, and climate change; and ecoinformatics. He helped lead efforts to develop a diatom BCG approach for the state of New Jersey.

Rex L. Lowe, Ph.D. Professor Emeritus of Biological Sciences, Bowling Green State University

Rex Lowe received his Bachelor of Science and Doctor of Philosophy degrees in botany at Iowa State University. He is currently Professor Emeritus at Bowling Green State University (BGSU) where he has won awards for outstanding teaching and research. Dr. Lowe teaches courses on Freshwater Algal Ecology, Limnology and Great Lakes Ecosystems. In addition to BGSU, Dr. Lowe also teaches in the summers at The University of Michigan Biological Station, Michigan State University's Kellogg Biological Station and Ohio State University's Stone Laboratory and has recently moved to the Center for Limnology at the University of Wisconsin. In 2008 Lowe was awarded the Wilder Chair for a distinguished botanist at the University of Hawaii where he studied freshwater algal endemics. In 2014 he was awarded the prestigeous Award of Excellence from the Phycological Society of America for sustained research excellence. Professor Lowe has trained and graduated over 70 graduate students including 16 PhDs. Lowe's scholarly books and manuscripts (> 150) cover topics concerning algal ecology and diatom systematics.

Robert Sheath, Ph.D., Department of Biological Sciences, California State University San Marcos

Dr. Robert Sheath is a professor of the Department of Biological Sciences at California State University San Marcos. His research interests focus on the evolution, ecology, biogeography and systematics of freshwater algae and their use as water quality indicators. This research involves a combination of field and laboratory work, including advanced microscopy and molecular analyses. Dr. Sheath is the past Editor of the *Journal of Phycology* and a co-editor of *Freshwater Algae of North America: Ecology and Classification*. 2nd ed. An algal genus was named in his honor, *Sheathia*, and is distributed in North America, Europe and New Zealand. The lab was named California Primary Algae Lab by the California Water Board because it has the expertise, including adding considerably to the state flora, naming 4 new species to science and creating a widely accessible web site.

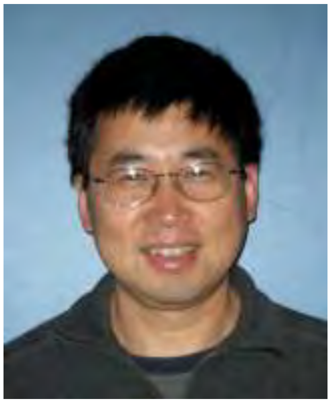
Sarah Spaulding, Ph.D., USGS, INSTAAR, University of Colorado, (http://instaar.colorado.edu/~spauldis/)

Sarah is an Ecologist for the US Geological Survey, working on the National Water Quality Assessment program. She works with an excellent group of taxonomists at INSTAAR, University of Colorado, focusing on improving the process of assessment in streams and rivers. Sarah is the Chair of the Editorial Review Board for a national diatom flora in the form of an online database, Diatoms of the United States. Sarah would like everyone to know about diatoms, particularly analysts and managers, and for all of us to work towards improving biotic condition in freshwaters.

Rosalina Stancheva Hristova, Ph.D., Department of Biological Sciences, California State San Marcos.

Dr. Rosalina Stancheva is a chief scientist at the California Primary Algae Laboratory of the Surface Water Ambient Monitoring Program (SWAMP) of the State Water Board at California State University San Marcos. She received a PhD in Phycology from the Sofia University, Bulgaria in 2004 where she was teaching courses in systematics of algae and fungi, ecology of algae, and diatom analysis. In 2005 she began doing research on diatoms from streams in the western USA for the US Environmental Protection Agency's Environmental Monitoring and Assessment Program. In the past 9 years she has been developing soft-bodied algae and diatoms as bioindicators for stream in California as part SWAMP, including standard laboratory and quality control operating procedures, online taxonomic identification tool and algal index of biotic integrity. Her research centers on freshwater algae taxonomy, ecology, and biogeography, diversity of nitrogen-fixing and toxin-producing cyanobacteria in streams in California. She discovered four new to science freshwater species of green algae from SWAMP data set. Recently her studies are focused on the stream diatom flora in California.

Yangdong Pan, Ph.D. Department of Environmental Science and Management at Portland State University (PSU).



Dr. Yangdong Pan is professor of the Department of Environmental Science and Management at Portland State University (PSU). His research centers on freshwater ecology and conservation. Specifically, he uses algal assemblages to monitor and assess ecological risk in freshwater ecosystems including lakes, wetlands and rivers. He has participated several national surface water quality programs such as the US Environmental Protection Agency's Environmental Monitoring and Assessment Programs (EMAP) in the Mid-Atlantic Region and in the western USA with a focus on periphyton indicators development. Recently, he has been collaborating with Chinese environmental professionals on several water-quality projects including ecology and management of algal blooms in shallow lakes, drinking water source protection, and ecological risk assessment of lakes and streams in the Jiuzhaigou National Park, a UNESCO world natural heritage site. He teaches limnology, freshwater algae, ecology of streams/river, and two graduate-level courses on environmental and biological data analysis.

Benthic Macroinvertebrate Taxonomy and Ecologists

Larry Brown, Ph.D., Research Biologist, USGS, California Water Science Center. https://profile.usgs.gov/lrbrown.

Larry R. Brown is a Research Biologist with the U.S. Geological Survey, California Water Science Center. Dr. Brown has over 35 years of experience working in California aquatic systems. He is a recognized expert on the ecology of California fishes and has published on California fishes, benthic macroinvertebrates and benthic algae. Dr. Brown is currently involved in studies of the effects of climate change on selected fish species in the Central Valley watershed and San Francisco Estuary, factors associated with declines in pelagic fish populations of the San Francisco Estuary, and effects of hydrologic alteration on California stream systems. In the course of his work, Dr. Brown has authored or coauthored over 80 scientific articles and reports.

Jim Carter, Research Scientist, USGS Menlo Park, CA.

Jim Carter is a researcher for the National Research Program (Water Mission Area) of the U.S. Geological Survey. He has held this position at the western region center in Menlo Park, CA since 1981. He has a Ph.D. from the Department of Entomology, University of California, Berkeley. His research has focused on numerous aspects of aquatic ecology. Lotic studies have emphasized: 1) determining the influence of fluvial geomorphology and landscape characteristics on the distribution of stream benthic invertebrates at a variety of spatial and temporal scales and 2) identifying the effects of sample collecting, processing and analyzing on the interpretation of lotic bioassessments. Lentic studies include comprehensive research on the benthic fauna of a western hypereutrophic lake (Upper Klamath Lake, OR). These studies have emphasized: 1) identifying factors that influence the large and small scale spatial and temporal distribution of invertebrates, 2) determining the effects benthic invertebrates have on nutrient cycling, and 3) developing a lake food web model using stable isotopes of carbon, nitrogen, and sulfur.

David Herbst, Ph.D., Research Scientist, UC Santa Barbara, Sierra Nevada Aquatic Research Laboratory.

Dave Herbst received a PhD in zoology and entomology from Oregon State University in 1986 and has been a research scientist with UC Santa Barbara since that time, stationed at the Sierra Nevada Aquatic Research Laboratory. My early research was mainly on the physiology and ecology of invertebrates from saline lakes (Mono and Owens Lakes in California, Abert in Oregon, Walker and Big Soda in Nevada), using comparative ecology and field and lab experiments to study effects of salinity. In the 1990s I began doing research on BMIs in streams of the Sierra Nevada and worked for 15 years to develop a bioassessment program and indicators for the eastern Sierra and central coast regions of California. My stream research spans long-term studies of the effects of sediment deposition, acid mine drainage, livestock grazing, habitat restoration, forest management, introduced species (trout, New Zealand mud snail), and monitoring of climate change and drought in Sierra Nevada headwaters.

Jeanette Howard, Ph.D., Associate Director of Science, Water Program, the Nature Conservancy.

Jeanette Howard, PhD, Associate Director of Science, Water Program, The Nature Conservancy, California. Dr. Howard leads TNC's freshwater science engagements which focus on developing and fostering a science enterprise to sustain healthy aquatic ecosystems in California. This work includes conservation planning for freshwater biodiversity statewide, defining environmental flows for water policy and management, and on-the-ground research projects to evaluate conservation actions.

Bill Isham, Senior Ecologist, AMEC Foster Wheeler, San Diego CA

Mr. Isham received a bachelors degree in Biological Sciences from Florida Institute of Technology. He has worked for private environmental consultants since 1991, including MEC Analytical (1991-2005), Weston Solutions (2005-2014), and Amec Foster Wheeler (2014-present). Mr. Isham has 25 years of experience in freshwater stream, marine, and wetland ecology. He has extensive project management experience with active participation in every phase of environmental monitoring including survey design, field collections, laboratory sample analyses and taxonomy, data management/interpretation, and reporting. As a taxonomist, he specializes in freshwater aquatic insects as well as marine and freshwater fish (adult and larval stages). Since 2001, he has been, at various times, the director for regional NPDES permit compliance stream bioassessment programs in San Diego, Orange, Los Angeles and Riverside counties and is familiar with every major watershed in southern California. He has managed numerous monitoring projects related to stream and wetland restoration, mitigation, spill impacts, construction and BMP effectiveness, overseeing multidisciplinary efforts for baseline, performance and impact monitoring. He has also contributed to NEPA/CEQA documents, EIR/EIS's, Biological Opinions, and habitat management and restoration plans.

Jason May, Aquatic Ecologist, USGS California Water Science Center.
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Jason T. May is an aquatic ecologist with the U.S. Geological Survey, California Water Science Center. Mr. May has over 14 years of experience working in California aquatic systems. He has published on California fishes, benthic macroinvertebrates and benthic algae. Mr. May is currently involved in studies of the effects of urbanization on stream systems across the United States, modeling of responses of stream macroinvertebrate communities to land use changes, and investigations of mercury and other trace metals contamination associated with abandon mine lands. In the course of his work, Mr. May has authored or coauthored over 30 scientific articles and reports.

Patina Mendez, Ph.D., UC Berkeley's Environmental Sciences Program.

Dr. Patina Mendez is freshwater ecologist and a Continuing Lecturer for UC Berkeley's Environmental Sciences Program. She is a specialist in the life history characteristics (e.g., life cycle timing, feeding, reproductive strategies, etc.) of freshwater invertebrates and how they are linked with habitat. She also investigates models of benthic macroinvertebrate community structure using life history traits in spatially large datasets. Her taxonomic area is caddisflies (Trichoptera), a group of insects that spend most of their life cycle in an aquatic larval stage that builds a case or retreat. Her projects include using distribution records of caddisflies in California streams to help broaden understanding of species diversity and changes in distributions over the past 100 years. She is also a curator of the Trichoptera Literature Database, a bibliography of 14,000 references on Trichoptera.

Allison O'Dowd, Ph.D., Associate Professor, Environmental Science and Management, Humboldt State University.

Dr. Alison O'Dowd is an Associate Professor in the Department of Environmental Science and Management at Humboldt State University and Co-Director of the HSU River Institute. Dr. O'Dowd has conducted research in the fields of stream ecology and restoration for over 15 years. Dr. O'Dowd's specific research areas include: the development of biological condition gradients in urban watersheds, stream and wetland restoration, the ecology and eradication of invasive species, the impacts of wildfire on stream communities, the biological significance of step-pool sequences in mountain streams, and the management of dam releases to assist migrating salmonids. Dr. O'Dowd's research methods use benthic macroinvertebrates as indicators of water quality in urban and natural freshwater ecosystems. Dr. O'Dowd's research is primarily located within California, with a focus on California's North Coast. Study areas include: the Eel River, Smith River, Klamath River, Lake Tahoe Basin, and Humboldt Bay and San Francisco Bay watersheds.

John Olson, Ph.D. Assistant Professor, California State Monterey Bay.

John Olson completed his PhD in Watershed Science at Utah State University and postdoctoral studies at the Desert Research Institute. He is currently an assistant research professor at the Desert Resarch Instiute, and is joining the faculty at Cal State Monterey Bay in January 2017. His research focuses on understanding how landscape patterns in geology, climate, vegetation and other environmental factors affect surface water chemistry; how differences in water chemistry in turn affect stream biota; and how these relationships can be applied to managing freshwater resources. He has worked with US EPA, USGS, and natural resource agencies in Georgia, Utah, Wyoming, Wisconsin, and Oregon to improve bioassessments of streams and rivers. Some of his recent projects include empirically modeling natural water chemistry to establish water chemistry baselines and nutrient criteria nationwide, determining how invertebrate distributions are affected by geology, and developing predictive models of fish and algae distributions based on environmental DNA samples and remote sensing data.

Andy Rehn, Ph.D., Research Biologist, California Department of Fish & Wildlife Aquatic Bioassessment Lab (ABL)

Andrew Rehn earned a PhD in Entomology from UC Davis in 2000 and has been a biologist with the California Department of Fish & Wildlife Aquatic Bioassessment Lab (ABL) for the last 16 years. At ABL he helped develop several of the state's first biological indices and led studies on spatial variability in bioassessment samples and comparability of samples collected by different methods. Special research interests have included the effects of hydropower dams and wildfires on aquatic macroinvertebrates. More recently he co-authored the California Stream Condition Index by creating models to relate natural environmental variability to species distributions. He is the lead coordinator of the statewide Perennial Stream Assessment and the statewide Reference Condition Monitoring Plan. As a founding member of the Southwest Association of Freshwater Invertebrate Taxonomists and the California Freshwater Algae Working Group, he has played a leading role in establishing the state's taxonomic data quality standards for bioassessments, which have become a model for national programs.

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BRIDGES

BRIDGES is a recurring feature of J-NABS intended to provide a forum for the interchange of ideas and information between basic and applied researchers in benthic science. Articles in this series will focus on topical research areas and linkages between basic and applied aspects of research, monitoring, policy, and education. Readers with ideas for topics should contact Associate Editors Nick Aumen and Marty Gurtz.

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Challenges and prospects for restoring urban streams: a perspective from the Pacific Northwest of North America

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Abstract. Undoing harm caused by catchment urbanization on stream channels and their resident biota is challenging because of the range of stressors in this environment. One primary way in which urbanization degrades biological conditions is by changing flow patterns; thus, reestablishing natural flow regimes in urban streams demands particular attention if restoration is to have a chance for success. Enhancement efforts in urban streams typically are limited to rehabilitating channel morphology and riparian habitat, but such physical improvements alone do not address all factors affecting biotic health. Some habitat-forming processes such as the delivery of woody debris or sediment may be amenable to partial restoration, even in highly disturbed streams, and they constitute obvious high-priority actions. There is no evidence to suggest, however, that improving nonhydrologic factors can fully mitigate hydrologic consequences of urban development. In the absence of effective hydrologic mitigation, appropriate short-term rehabilitation objectives for urban channels should be to 1) eliminate point sources of pollution, 2) reconstruct physical channel elements to resemble equivalent undisturbed channels, and 3) provide habitat for self-sustaining biotic communities, even if those communities depart significantly from predisturbance conditions. Long-term improvement of stream conditions is not feasible under typical urban constraints, so large sums of money should not be spent on unrealistic or unreachable targets for stream rehabilitation. However, such a strategy should not be an excuse to preclude potential future gains by taking irreversible present-day development or rehabilitative actions.

Key words: stream enhancement, urbanization, rehabilitation, restoration, watershed hydrology, aquatic invertebrates, land cover.

Catchment urbanization has long been known to harm aquatic systems, but reversing the degradation imposed on the physical channel and resident biota remains elusive. Other papers in this series focus on particular aspects of urban stream degradation; my intent is to emphasize what may be needed to reduce such degradation and to acknowledge constraints on successful restoration in urban catchments. Those constraints are not well incorporated into management goals for urban streams; all too commonly, urban systems become orphans of neglect (i.e., ''nothing can be done'') or, conversely, of unrealistic optimism (e.g., ''the salmon will return''). Review of recent studies, however, suggests that other perspectives may be warranted that offer both promising and achievable outcomes.

The context of my discussion is temperate, humid-region lowland streams where urban or suburban development is the primary human disturbance. Most of my examples are taken from the Puget Sound region of western Washington, with the city of Seattle as the geographic and demographic center. The climate is maritime and mild, with 75% of the annual rainfall (~1000 mm) falling in autumn and winter.

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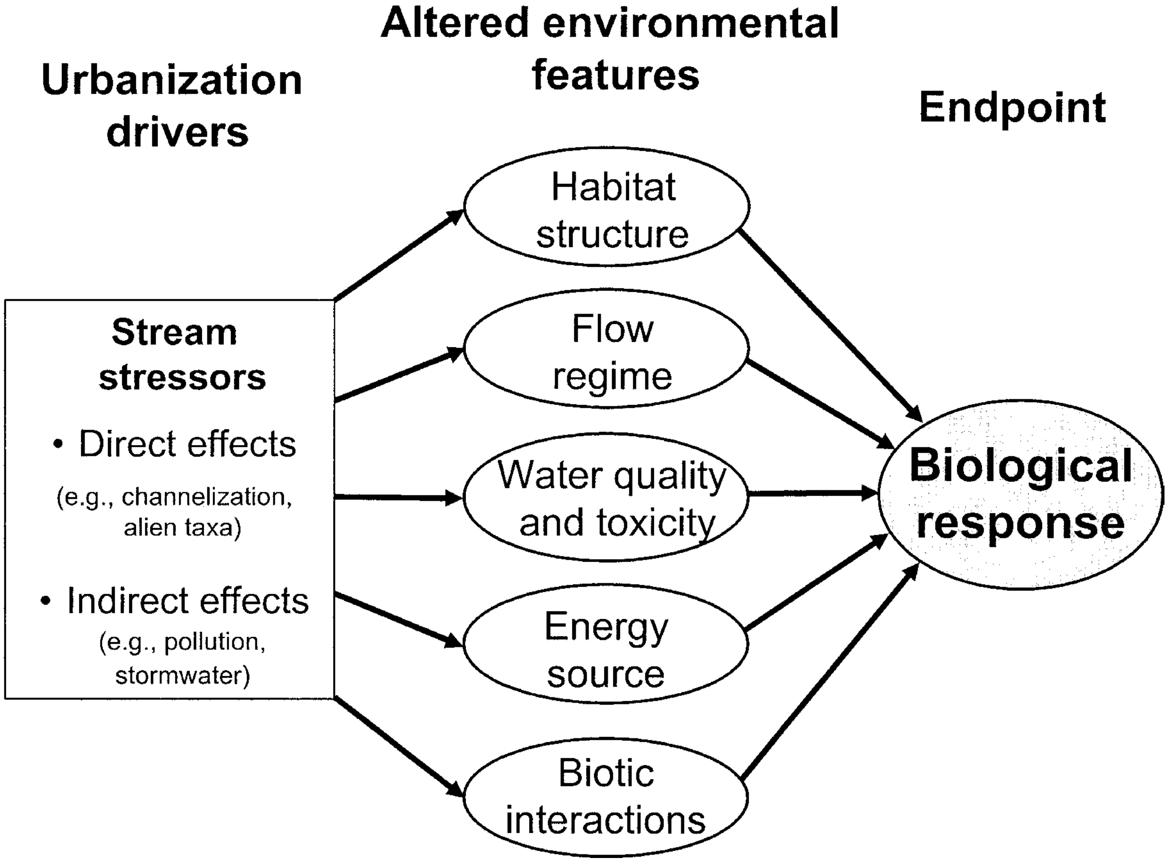

FIG. 1. Five environmental features that are affected by urban development and, in turn, affect biological conditions in urban streams (from Booth et al. 2004, reprinted with permission of the American Water Resources Association; modified from Karr 1991, Karr and Yoder 2004).

Catchments in this region share relatively uniform soil, climate, and topography, allowing direct comparisons among streams. All study streams have, or once had, diverse natural biota, including anadromous salmonids; even streams in moderately developed catchments still support valuable biotic resources that are protected by local, state, and/or federal laws, and are widely appreciated by the public. State and local government expenditures for stream enhancement have expanded dramatically over the past decade because of both legal requirements and public support, reflecting increased social and political interest (National Marine Fisheries Service 2004, WDFW 2004).

Many human actions can disrupt the chemical, physical, and biological processes that influence stream biota. These processes, and their interactions, can be grouped into 5 classes of environmental features (Fig. 1; Karr et al. 1986, Karr 1991, NRC 1992, Yoder and Rankin 1998). This classification provides a tractable framework for analyzing the condition of water resources such that, when one or more environmental feature is affected by human activities, the result is ecosystem degradation. Following Karr (1999), biological conditions are judged as either healthy or progressively less healthy compared with analogous reference conditions. Using an endpoint of biological integrity acknowledges, but does not concede, the damage already done by human intervention (cf. Rapport et al. 1998, Carpenter et al. 2003). However, no one environmental feature determines biological health a priori (Boulton 1999); conversely, improving any one feature does not guarantee improvement in biotic condition of the catchment as a whole.

Changes in the urban environment can be imposed on any or all of the above features by many human activities, through a number of pathways at multiple spatial scales (Walsh et al.

2005a). For example, changes in land cover integrated over an entire catchment will alter both stormwater inflows to streams and recharge of groundwater (Konrad et al. 2005). Adjacent to stream channels, changes to riparian land cover can affect localized input of energy from organic matter and sunlight; at a single site, the structure of the channel itself can be disrupted by direct modification.

Any of the 5 features shown in Fig. 1 can be responsible for reduced biological health in an urban stream, but changes in flow regimes, in particular, are an important pathway by which urbanization influences biotic conditions. This premise is based on the magnitude of change in hydrology commonly imposed by urbanization (Hollis 1975, Leopold 1968, Booth and Jackson 1997, Konrad and Booth 2002) and the close connection between stream biological health and hydrologic alteration (Power et al. 1988, Poff and Allan 1995, Resh et al. 1988, Poff and Ward 1989, Horner and May 1999, Roy et al. 2005). My focus on the hydrologic regime in this paper should not imply that understanding hydrology allows a complete explanation for urban stream degradation; however, it does provide a useful starting point for evaluating stream-enhancement efforts in the Pacific Northwest and, likely, for other humid-area regions of the world. Flow is a key factor in aquatic systems and one that is almost universally altered by urban development, so it demands particular attention if stream restoration is to have any chance of success.

Chemical water-quality alteration has received considerable attention in urban streams (Paul and Meyer 2001). However, data from all but the most highly urbanized catchments in the Pacific Northwest suggest no clear relationships between a broad suite of conventional water-chemical parameters and biological health (May et al. 1997, Horner and May 1999). Increases in conductivity and nutrients commonly are associated with increases in urbanization (May et al. 1997, Herlihy et al. 1998, Walsh et al. 2005a) but corresponding ecological effects are relatively weak, closely correlated with hydrologic responses, and generally cannot be explained solely in relation to chemical water-quality standards.

The purpose of my paper is to review past and ongoing studies in terms of 1) assessing the prevalence and importance of hydrologic alteration in urban catchments, and 2) evaluating the nature and outcome of common enhancement approaches in urban streams. In combination, these studies suggest a framework for approaching urban stream restoration, in particular one that recognizes not only the importance of the hydrologic regime but also the unique constraints of the urban environment on achievable goals and objectives for restoration.

Sources of Data

Relationships between urban land cover, biological condition, and hydrology are evident in several studies across the Puget Lowland (see Booth et al. 2004), with data collected from 45 sites on 16 second- and third-order streams in King and Snohomish counties. Streams have similar catchment areas (5–69 km^2), local channel gradients (0.4–3.2%), soils, elevation, and climate typical of the central Puget Lowland, and urban development as the dominant human activity (American Forests 1998). Total imperviousness (TI, the % of a catchment covered by impervious surfaces) was used to characterize degree of urban development in the catchments draining to each site; TI values were determined from a classified 1998 Landsat image (30-m resolution; Hill et al. 2003). Paved land cover in the contributing catchments ranged from near 0 to almost ⅔.

Benthic macroinvertebrate assemblages were sampled at all 45 sites from 1997 to 1999 (Morley and Karr 2002). The biological condition of each site was quantified by the 10-metric benthic index of biotic integrity (B-IBI, Karr 1998), which includes measures of taxon richness, tolerance to disturbance, and selected ecological attributes (e.g., proportion of clingers and predators). Hydrologic analyses were conducted at all of the macroinvertebrate sites that were close to gauging stations and without intervening input of tributaries (n = 18 total sites; Konrad 2000). Equivalent hydrologic analyses also were conducted for 10 additional lowland streams with similar gradients and catchment geology, but some with catchment areas up to 171 km^2, to allow a more thorough assessment of the influence of contrasting catchment urbanization on flow regime.

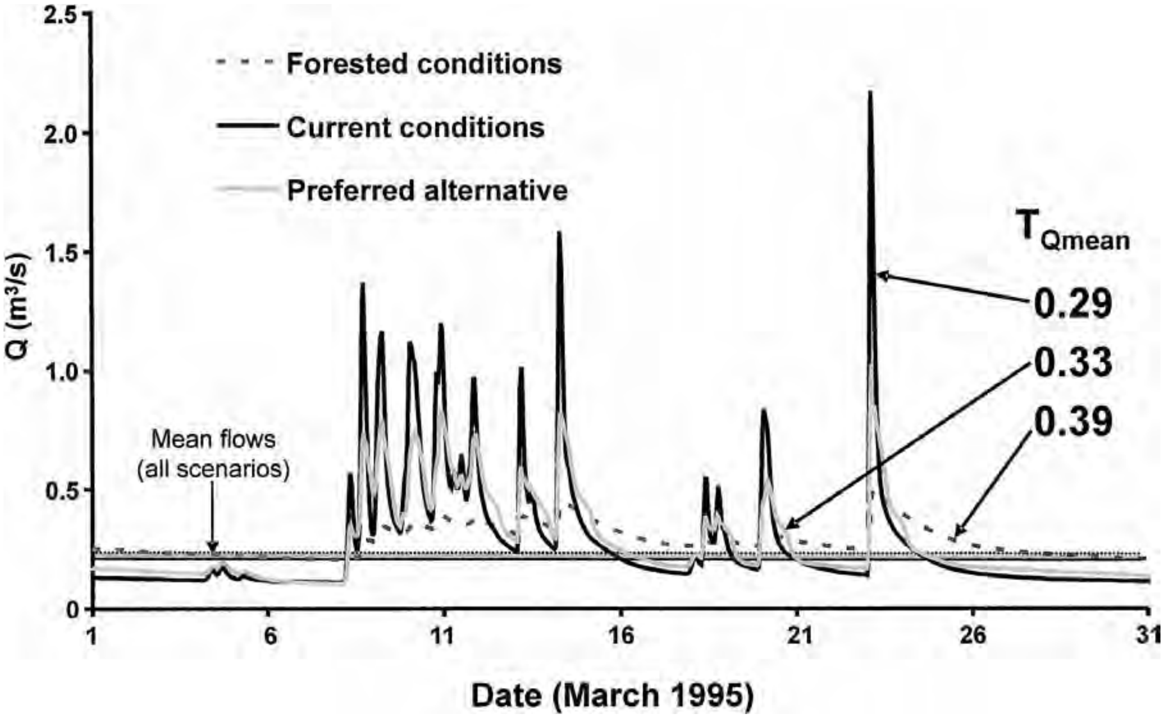

FIG. 2. Example of variation in the fraction of a year daily mean discharge exceeds annual mean discharge (T_{Qmean}) as a result of urban development, displayed with simulated hydrographs for Des Moines Creek in the central Puget Lowland (lat ~47°24′N, long 122°20′W). Hydrographs and corresponding values of T_{Qmean} compare predevelopment (forested) condition for this 14-km² catchment, current (degraded) condition, and full catchment urbanization with a hypothetical detention pond and high-flow bypass pipeline (preferred alternative; estimated cost = $8 million US). Simulation results courtesy of King County Department of Natural Resources (King County 1997). Note that traditional hydrologic mitigation (i.e., preferred alternative) effectively reduces flood peaks, but its influence on T_{Qmean} values is significantly less pronounced.

Quantifying Hydrologic Alteration

Changing flow patterns over time scales of months to years potentially imposes a long-term regime of frequent disturbances to stream biota (e.g., Pickett and White 1985, Poff et al. 1997). In contrast, the long-term ecological consequences of a single 1- or 2-d flood are likely to be unimportant because episodic high flows are part of most riverine systems, irrespective of human disturbance. Published hydrologic statistics that represent long-term storm and baseflow patterns relevant to stream biota include baseflow stability, daily discharge variability, and spate frequency (Poff and Allan 1995); the ratio of flood-to-baseflow volume, the frequency of high flows, and the product of frequency and duration of high flows (Clausen and Biggs 1997); and the fraction of a year daily mean discharge exceeds annual mean discharge (T_{Qmean}) (Konrad and Booth 2002, Konrad et al. 2005).

T_{Qmean} provides an intuitive index of urban influence on flow regimes because it reflects the annual or decadal distribution of runoff between storm flow and base flow. As such, it reflects the degree of flashiness in a stream hydrograph (Fig. 2). T_{Qmean} is expected to decrease with urban development because annual mean discharge changes little in response to urbanization, whereas duration of individual flood peaks shortens greatly (Konrad and Booth 2005). This metric was used to characterize hydrologic conditions in the study catchments because of its demonstrated responsiveness to urbanization.

The correlation of biological conditions (as B-IBI) with T_{Qmean} in the Puget Lowland study sites was about as good as with TI ($R^2 = 0.67$ for B-IBI vs T_{Qmean}, $R^2 = 0.70$ for B-IBI vs TI, both $p < 0.001$; Booth et al. 2004). However, T_{Qmean} is a more useful parameter than TI for understanding degradation processes because it more closely represents a likely causal mechanism for stream degradation. T_{Qmean} is not a gross measure of human disturbance, but instead expresses a disturbance signal for a specific environmental feature (e.g., Roy et al. 2003). Urban stream degradation has multiple causes, but the consistency of the B-IBI–T_{Qmean} relationship coupled with the ubiquity of hydrologic alteration in urban and urbanizing catchments (Booth and Jackson 1997) suggest that hydrologic alteration is a fundamental determinant of biotic changes in these systems.

Historical Approaches to Restoring and Rehabilitating Urban Streams

Goals for stream enhancement projects vary both spatially and temporally. They are sometimes articulated in terms of restoration, namely the return to predisturbance conditions (Cairns 1989). More typically, however, such goals offer only the more modest objective of rehabilitation, the measurable improvement of a limited number of elements, with the associated hope of some overall improvement in stream biological health. In either scenario, the focus is typically on the channel's physical condition, with little or no corresponding evaluation of the biological response. Yet, synoptic reviews and specific examples both demonstrate the inadequacy of physical enhancement approaches alone.

Bethel and Neal (2003) noted the following prevailing goals for stream-enhancement projects in the Puget Sound region: ''1. to establish the channel morphology appropriate to the topographic, geologic, and hydrologic setting, and 2. to establish the channel and riparian habitat that support a diverse native plant and animal community appropriate to the setting''. This perspective was affirmed by most stream-enhancement projects in the Puget Sound region during the 1990s (CUWRM 1998). Of the nearly 400 stream-enhancement projects reviewed in CUWRM (1998), 90% fell into 4 broad categories involving physical rehabilitation: riparian enhancement (planting and fencing; 35% of all projects), instream habitat augmentation (large woody debris [LWD] installation, gravel placement, and large rocks; 22%), bank stabilization and grade control (18%), and fish passage enhancement (15%). Each of these project categories typically affects only a few tens to, at most, hundreds of meters of stream channel. The CUWRM (1998) study also reported very limited construction of flow-control projects such as regional detention ponds, presumably because of their high financial and environmental cost (e.g., King County 1994) and dubious effectiveness in hydrologic restoration (Booth and Jackson 1997). In this context, Fig. 2 is an example of how very high project cost results in only modest hydrologic improvement. More integrative and potentially more effective flow-control strategies, notably low-impact development (LID; USEPA 2000) or the disconnection of impervious surfaces from the stream network (Walsh 2004, Walsh et al. 2005a), are poorly represented by projects during this period (CUWRM 1998), although implementation is now becoming more widespread (e.g., Puget Sound Action Team 2003).

Despite the high abundance of stream-enhancement projects, reported evaluations are remarkably limited, and available monitoring results are not very encouraging (Beschta et al. 1994, Kondolf and Micheli 1995). For example, Frissell and Nawa (1992) evaluated rates and causes of physical impairment or failure for 161 fish-habitat structures in 15 streams in southwest Oregon and southwest Washington. Their study catchments generally had been affected more by logging rather than by urbanization, yet despite this generally less severe form of catchment disturbance, functional impairment and outright project failure was common (median damage rate = 60% following a single flood, with a 2- to 10-y recurrence interval; Frissell and Nawa 1992). In particular, Frissell and Nawa (1992) found that damage to restoration projects was most widespread in streams with signs of recent catchment disturbance, high sediment loads, and unstable channels. They argued that restoration of alluvial streams with the greatest potential for fish production in the Pacific Northwest requires reestablishment of natural catchment and riparian processes rather than the construction of instream features. Larson et al. (2001) reviewed 6 projects in which LWD was placed into small suburban and urban streams and reported that these projects produced, at best, only modest changes in channel structure but generally no improvement in biological condition. Hession et al. (2003) reported that urban stream reaches with forested riparian corridors in Pennsylvania and Delaware displayed differences in a few benthic macroinvertebrate metrics compared with nonforested sites, but only at the lowest levels of catchment TI. The common theme of these and other stream-restoration projects is their narrow symptomatic focus (e.g., bank erosion or lack of pools or LWD at a site) in response to an underlying disturbance at a much larger, typically catchment scale (e.g., logging or urbanization).

Anecdotal examples graphically demonstrate the challenges involved in restoring streams using only symptomatic, local-scale approaches. Madsen Creek drains 6 km^2 of largely urban and suburban upland plateau in the Puget Lowland, ~20 km southeast of Seattle. In 1989, the lowermost kilometer of the channel was relocated as part of a road-widening and fish-enhancement project designed to recreate salmon-spawning habitat. The stated project objective was simply to deploy the specified quantities of logs, stumps, riparian plants, and streambed gravel to the site. Logs and rootwads were placed in the channel, gravel of a size deemed suitable for salmon spawning was spread over the bed, and fast-growing native riparian species were planted along the banks (Fig. 3A). A large rainstorm that winter created significant flooding and erosion in the stream, and erosion of a steep ravine below the upland deposited hundreds of m^3 of sand and silt throughout the project reach that destroyed most of the constructed habitat elements (Fig. 3B). Eight years of relatively benign flows later, the channel offers an instructive case both for and against site-scale rehabilitation (Fig. 3C): the riparian corridor is healthy and provides shade, litter, and protection to the stream, but the large manmade structures are either buried or eroded, and the channel bed remains sandy, ill-suited for salmon spawning, and reflects the sediment load of the upper catchment under present flow and erosion conditions. The project achieved only a subset of its goals, but not necessarily those of greatest concern or those that required the most costly actions.

Longfellow Creek, draining a heavily urbanized catchment in Seattle, provides another example of a local-scale action motivated by broad ecological goals but, at best, showing only marginal success. In- and nearstream projects to date on a 2-km reach include removing fish-migration barriers, planting riparian vegetation, reconstructing the channel, addition of spawning gravel, and placement of instream LWD (Fig. 4), for a cost of $8 million US. Post-restoration biotic conditions, however, have yielded massive pre-spawning death of returning (or stray) coho salmon (Seattle Post-Intelligencer 2003), with only a small fraction of salmon surviving long enough to spawn, and with virtually no smolt production (Fig. 5).

Consequences for Urban Stream Restoration

Habitat elements and habitat-building processes

The lessons of Madsen and Longfellow creeks and elsewhere are clear and should not be surprising. Certain instream conditions are easier to improve than others, but local actions cannot reverse the consequences of broadly degraded urban catchments. Given the financial and technological obstacles to fixing catchment-scale degradation, particularly hydrologic alteration, urbanization often promotes the inescapable consequence of limiting efficacy of local-scale actions (Barker et al. 1991, Booth and Jackson 1997, Maxted and Shaver 1999, Booth et al. 2002, Morgan and Cushman 2005).

The difficulty in managing multiple scales of degradation has long been explored in forestry-dominated landscapes, where the distinction between aquatic-habitat ''elements'' and habitat-building ''processes'' usefully discriminates the construction of channel features from the establishment of self-sustaining improvements (Cederholm et al. 1997, Roni et al. 2002). For example, fish habitat in Pacific Northwest streams includes such elements as LWD, pools, riparian and instream cover, gravel deposits, floodplains, and riparian vegetation. Each of these habitat elements can be built on-site, but neither their longevity (Frissell and Nawa 1992) nor their biological effectiveness (Larson et al. 2001) can be documented. Roni and Quinn (2001) noted that streams subject to outmoded forest practices and with initially low amounts of instream wood generally showed the most dramatic increases in habitat quality and fish abundance following local-scale LWD introductions. This outcome is logical for channels where the absence of LWD occurred primarily by physical removal (e.g., Collins et al. 2003). Yet, catchment processes that create and must permanently support such features (i.e., forest succession, sediment input, flow regime, geomorphic evolution of alluvial channels) operate at such broad

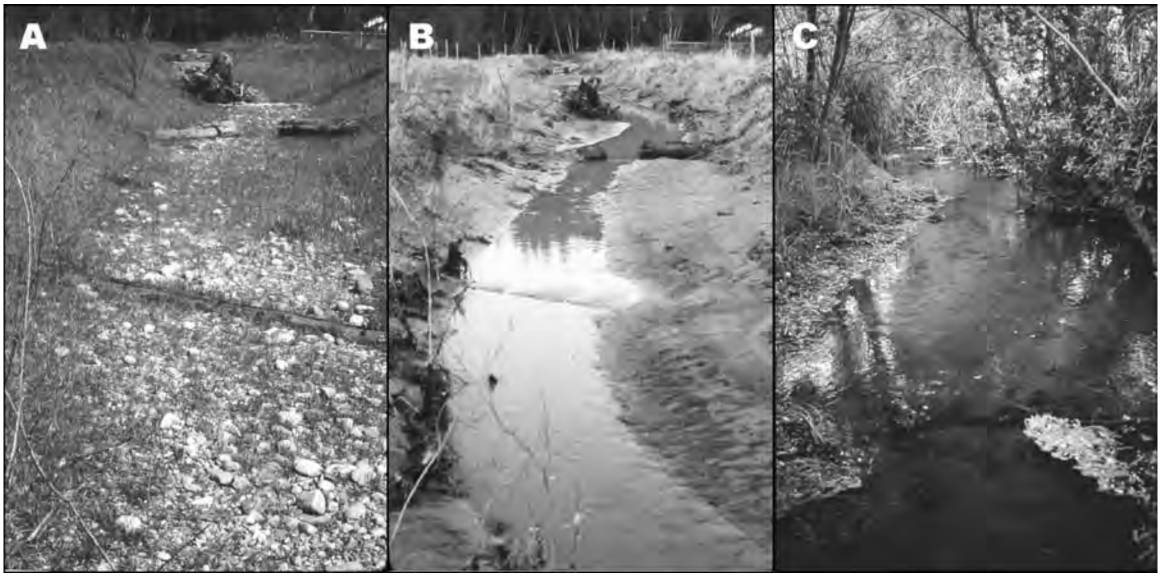

FIG. 3. Reconstruction, disturbance, and partial recovery of lower Madsen Creek, southeast of Seattle, Washington. Photographs taken September 1989 (A), February 1990 (B), and April 1998 (C).

FIG. 4. Longfellow Creek, in the city of Seattle, Washington, shortly after channel reconstruction with log deflectors, imported channel-bed sediment, and riparian plantings.

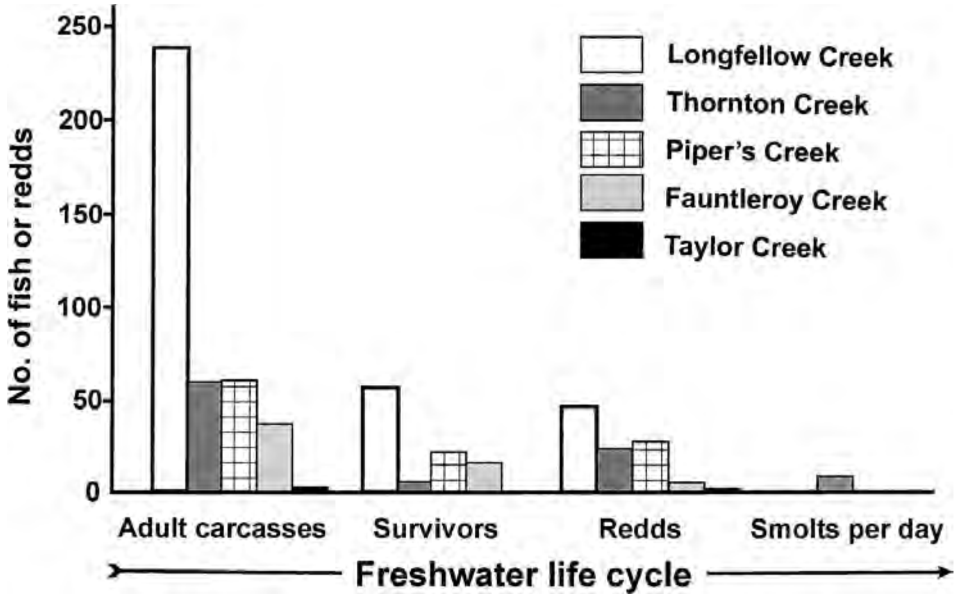

FIG. 5. Decline in survival at successive life stages of coho salmon in the 5 major streams of Seattle, Washington (2003 data from the City of Seattle).

spatial and temporal scales that their products will not persist if simply built or replaced (Kauffman et al. 1997, Roper et al. 1997, Beechie and Bolton 1999, Kondolf et al. 2001), particularly in flashy, unstable urban systems.

Short- and long-term enhancement of urban streams

This distinction between habitat elements and habitat-building processes suggests an alternative perspective to urban stream enhancement: short- vs long-term restoration activities. The former actions are generally feasible under many different management settings but unlikely to produce permanent effects; they include riparian fencing and planting, water-chemistry source control, fish-passage projects, use of instream structures, and construction of social amenities. Short-term actions address acute problems typical to stream channels in urban and urbanizing catchments (Miltner et al. 2004) and so are normally worthwhile, although they only provide immediate solutions that are necessary yet are insufficient to restore biotic integrity.

Short-term actions also must acknowledge the presence of people in urban environments. Actions enhancing the quality of interactions between people and urban streams, particularly those justified in terms of quality of life or by their value as a public amenity, are likely to be supported and maintained; indeed, such actions commonly result in financial outlays far in excess of likely ecosystem benefits (Middleton 2001). Conversely, actions degrading or limiting interactions between surrounding human communities and streams are more likely to fail. This situation is particularly relevant for short-term actions because they often are unlinked to catchment processes and so typically require continued maintenance to achieve even their transitory objectives. Use of public education to guide community actions in maintaining sustainable and ecologically beneficial streams and stream-enhancement projects is sorely needed (Purcell et al. 2002), which is a particular urgency in the Pacific Northwest because most urban streams flow across private property and thus lie beyond the jurisdiction of public agencies (Schauman 2000).

In contrast, long-term actions are, by definition, self-sustaining, and they address catchment processes at their relevant scales. However, they also must address each potentially degraded environmental feature (Fig. 1) if they are to achieve enhanced biological health. Examples include landuse planning such as preserves or zoning (King County 1994), avoiding road- and utility-stream crossings (Avolio 2003), rehabilitating upland hydrology (e.g., stormwater rein-

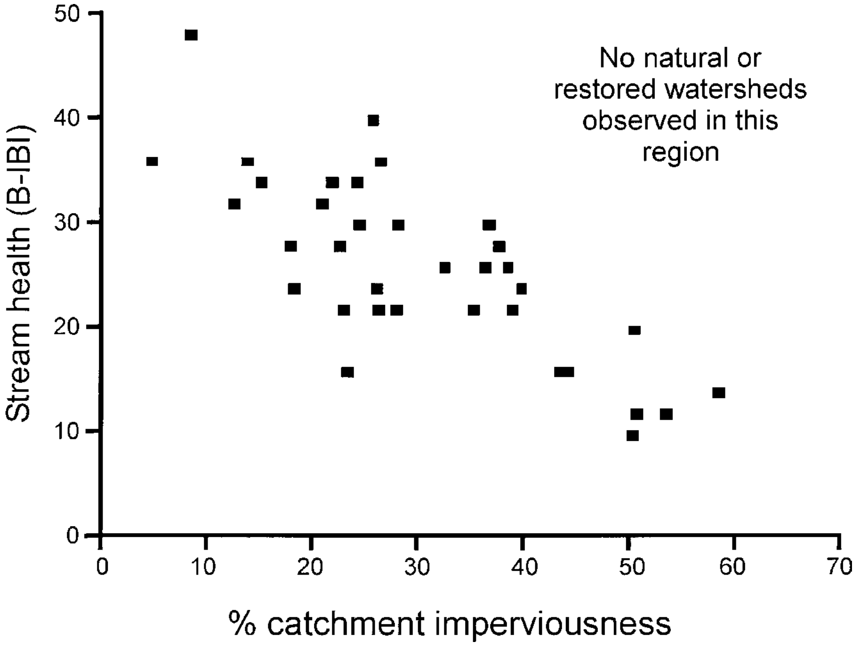

FIG. 6. Percent catchment imperviousness plotted against stream health (as benthic index of biotic integrity [B-IBI]) for Puget Lowland stream data. Management goals are commonly articulated for the upper right-hand corner of this graph (i.e., high-quality streams in highly urbanized watersheds), although no evidence suggests that this condition exists (modified from Booth et al. 2004; B-IBI data from Morley and Karr 2002).

filtration or LID; Walsh et al. 2005a), establishing riparian-zone vegetation communities, and reconnecting floodplains with their channels (Buffington et al. 2003).

Stewardship by the surrounding human community is as important with long-term as with short-term actions; however, it must emphasize instream biotic health over direct human interaction with stream channels (Schauman and Salisbury 1998). A long-term focus on enhancement, therefore, tends to exclude people from stream and riparian environments, even though enhancement requires social support to ensure ecological success. There are few examples or case histories to guide the development of this task.

Despite good intentions, strong public interest, and massive funds, we have virtually no examples of having achieved or retained biotic integrity—i.e., ecological health akin to that in undisturbed streams—in degraded urban channels. An example of this pattern comes from streams in the Puget Lowland (Morley and Karr 2002), where catchment imperviousness plotted against stream health (as B-IBI) showed no high-quality streams in highly urbanized catchments (Fig. 6). Clearly, we have not yet developed nor implemented a truly effective stream-enhancement strategy, a failure that echoes a long-recognized conclusion in ecological restoration regarding the challenge of achieving predisturbance ecosystem conditions in human-modified landscapes (Cairns 1989).

Towards better urban streams

The above perspective raises 2 key management questions for degraded urban catchments. First, can a natural flow regime ever be reestablished in an urban catchment and, if so, how? Second, if such a flow regime *cannot* be reestablished in urban catchments, what outcomes might be expected from other management actions that either construct short-term elements or reestablish some long-term processes (e.g., water-quality treatment, improved instream habitat, replanted riparian zone), but that do not address reestablishment of a natural flow regime?

A retrospective view suggests that the answer to the 1st management question is *no,* but failure of the last century's management of hydrologic alteration should not condemn us to the same future. Instead, it merely emphasizes the need for new approaches to stormwater management, preferably those integrating multiple scales of catchment planning, site layout, and infrastructure design. Such efforts are now beginning throughout the world (e.g., Puget Sound Action Team 2003, Walsh et al. 2005a), although their effectiveness is yet to be demonstrated. Determining the optimal combination and resulting effectiveness of such stormwater-management strategies should be a priority because their promise is great, alternatives are lacking, and confirmatory data for design guidance are presently sparse.

Yet full, or at least partial, long-term restoration of some habitat-forming processes, with subsequent biological recovery, may be possible even in highly disturbed urban environments. Such restorative actions include controlling of landslides and surface erosion to minimize changes to sediment-delivery processes, protecting mature riparian buffers to maintain delivery of coarse and fine organic debris and to moderate solar input (Jones et al. 1999, Parkyn et al. 2003), and disconnecting the pipes linking impervious areas to natural channels (Walsh et al. 2004, 2005a, b). For example, a B-IBI increase from ''very poor'' to ''fair'' over <2 km along a single suburban Puget Lowland stream channel was strongly explained by riparian land cover but not by overall catchment land cover (Morley and Karr 2002). Avolio (2003) and McBride and Booth (2005) have documented good correlations between physical condition of channels and frequency of stream-road crossings. Such results point to actions that are generally sensible to implement, even under existing management constraints, because they are often economically feasible and may provide long-term benefits. Furthermore, the absence of abrupt thresholds in biological responses to urbanization (e.g., Booth et al. 2002, Morley and Karr 2002) suggests that even incremental improvements can have direct, albeit commensurately modest, ecological benefits.

In the absence of effective hydrologic mitigation, however, what are appropriate objectives for urban streams (e.g., see also Osborne et al. 1993)? Point sources of pollution should be eliminated. In addition, channels should have the same physical elements (e.g., pools, substrate, logs, accessible floodplains) as their equivalent undisturbed counterparts, with the recognition that these elements are necessary but not sufficient to support future biotic improvements. Urban streams also should be considered neighborhood amenities that inspire passion and ownership from their nearby residents, and they can be self-sustaining to biotic communities, even though those communities depart significantly from predisturbance conditions.

Last, urban streams should also retain the possibility, however remote, of one day benefiting from the long-term actions that can produce greater, sustainable improvements. This final goal cannot be achieved for most urbanized catchments under present socioeconomic constructs, at least not in the Pacific Northwest. This constraint should be a reminder not to spend large sums of money on targets that can never be reached by paths that are all-too-commonly followed. This excuse is not sufficient, however, to continue building the kinds of urban developments or traditional rehabilitation projects that permanently preclude future long-term stream improvements.

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Derek Booth is a geologist and research professor at the University of Washington. He studies the causes of stream-channel degradation and the effectiveness of stormwater mitigation, in collaboration with many talented colleagues.

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BRIDGES

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Challenges and prospects for restoring urban streams: a perspective from the Pacific Northwest of North America

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Abstract. Undoing harm caused by catchment urbanization on stream channels and their resident biota is challenging because of the range of stressors in this environment. One primary way in which urbanization degrades biological conditions is by changing flow patterns; thus, reestablishing natural flow regimes in urban streams demands particular attention if restoration is to have a chance for success. Enhancement efforts in urban streams typically are limited to rehabilitating channel morphology and riparian habitat, but such physical improvements alone do not address all factors affecting biotic health. Some habitat-forming processes such as the delivery of woody debris or sediment may be amenable to partial restoration, even in highly disturbed streams, and they constitute obvious high-priority actions. There is no evidence to suggest, however, that improving nonhydrologic factors can fully mitigate hydrologic consequences of urban development. In the absence of effective hydrologic mitigation, appropriate short-term rehabilitation objectives for urban channels should be to 1) eliminate point sources of pollution, 2) reconstruct physical channel elements to resemble equivalent undisturbed channels, and 3) provide habitat for self-sustaining biotic communities, even if those communities depart significantly from predisturbance conditions. Long-term improvement of stream conditions is not feasible under typical urban constraints, so large sums of money should not be spent on unrealistic or unreachable targets for stream rehabilitation. However, such a strategy should not be an excuse to preclude potential future gains by taking irreversible present-day development or rehabilitative actions.

Key words: stream enhancement, urbanization, rehabilitation, restoration, watershed hydrology, aquatic invertebrates, land cover.

Catchment urbanization has long been known to harm aquatic systems, but reversing the degradation imposed on the physical channel and resident biota remains elusive. Other papers in this series focus on particular aspects of urban stream degradation; my intent is to emphasize what may be needed to reduce such degradation and to acknowledge constraints on successful restoration in urban catchments. Those constraints are not well incorporated into management goals for urban streams; all too commonly, urban systems become orphans of neglect (i.e., ''nothing can be done'') or, conversely, of unrealistic optimism (e.g., ''the salmon will return''). Review of recent studies, however, suggests that other perspectives may be warranted that offer both promising and achievable outcomes.

The context of my discussion is temperate, humid-region lowland streams where urban or suburban development is the primary human disturbance. Most of my examples are taken from the Puget Sound region of western Washington, with the city of Seattle as the geographic and demographic center. The climate is maritime and mild, with 75% of the annual rainfall (~1000 mm) falling in autumn and winter.

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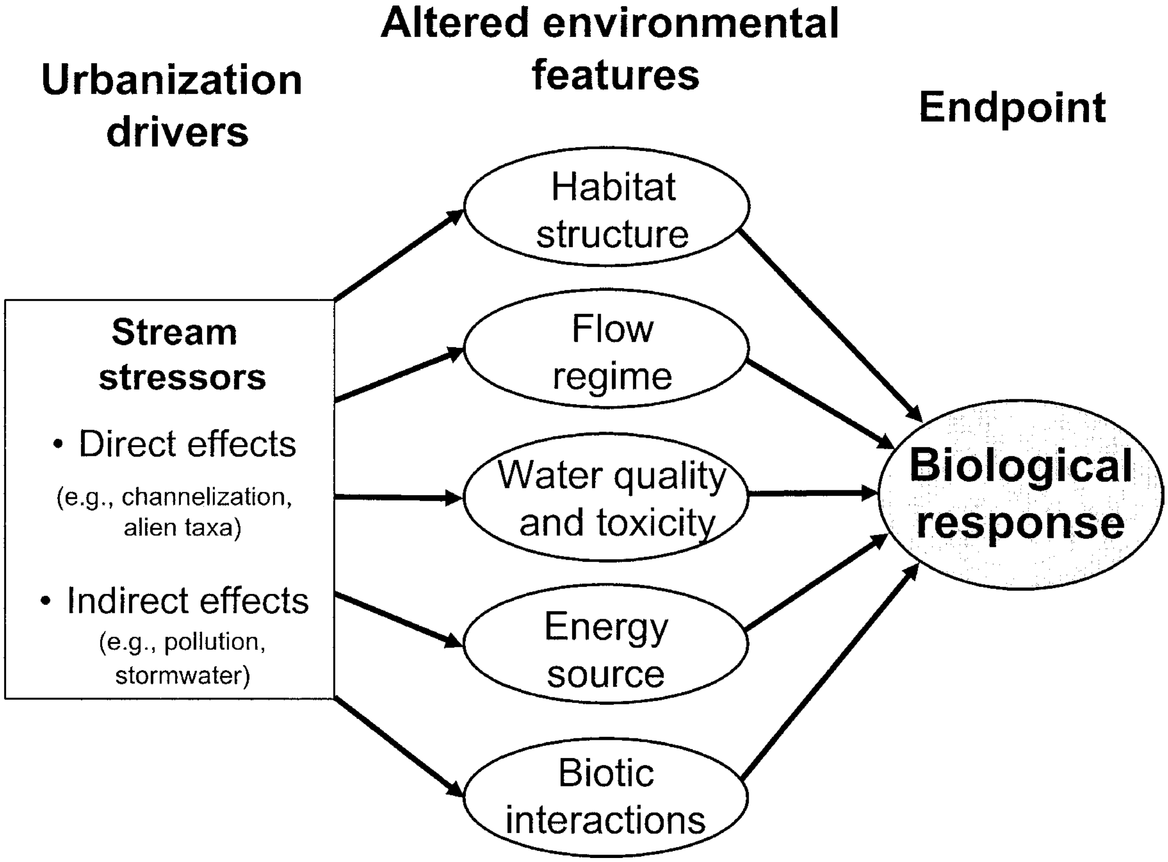

FIG. 1. Five environmental features that are affected by urban development and, in turn, affect biological conditions in urban streams (from Booth et al. 2004, reprinted with permission of the American Water Resources Association; modified from Karr 1991, Karr and Yoder 2004).

Catchments in this region share relatively uniform soil, climate, and topography, allowing direct comparisons among streams. All study streams have, or once had, diverse natural biota, including anadromous salmonids; even streams in moderately developed catchments still support valuable biotic resources that are protected by local, state, and/or federal laws, and are widely appreciated by the public. State and local government expenditures for stream enhancement have expanded dramatically over the past decade because of both legal requirements and public support, reflecting increased social and political interest (National Marine Fisheries Service 2004, WDFW 2004).

Many human actions can disrupt the chemical, physical, and biological processes that influence stream biota. These processes, and their interactions, can be grouped into 5 classes of environmental features (Fig. 1; Karr et al. 1986, Karr 1991, NRC 1992, Yoder and Rankin 1998). This classification provides a tractable framework for analyzing the condition of water resources such that, when one or more environmental feature is affected by human activities, the result is ecosystem degradation. Following Karr (1999), biological conditions are judged as either healthy or progressively less healthy compared with analogous reference conditions. Using an endpoint of biological integrity acknowledges, but does not concede, the damage already done by human intervention (cf. Rapport et al. 1998, Carpenter et al. 2003). However, no one environmental feature determines biological health a priori (Boulton 1999); conversely, improving any one feature does not guarantee improvement in biotic condition of the catchment as a whole.

Changes in the urban environment can be imposed on any or all of the above features by many human activities, through a number of pathways at multiple spatial scales (Walsh et al.

2005a). For example, changes in land cover integrated over an entire catchment will alter both stormwater inflows to streams and recharge of groundwater (Konrad et al. 2005). Adjacent to stream channels, changes to riparian land cover can affect localized input of energy from organic matter and sunlight; at a single site, the structure of the channel itself can be disrupted by direct modification.

Any of the 5 features shown in Fig. 1 can be responsible for reduced biological health in an urban stream, but changes in flow regimes, in particular, are an important pathway by which urbanization influences biotic conditions. This premise is based on the magnitude of change in hydrology commonly imposed by urbanization (Hollis 1975, Leopold 1968, Booth and Jackson 1997, Konrad and Booth 2002) and the close connection between stream biological health and hydrologic alteration (Power et al. 1988, Poff and Allan 1995, Resh et al. 1988, Poff and Ward 1989, Horner and May 1999, Roy et al. 2005). My focus on the hydrologic regime in this paper should not imply that understanding hydrology allows a complete explanation for urban stream degradation; however, it does provide a useful starting point for evaluating stream-enhancement efforts in the Pacific Northwest and, likely, for other humid-area regions of the world. Flow is a key factor in aquatic systems and one that is almost universally altered by urban development, so it demands particular attention if stream restoration is to have any chance of success.

Chemical water-quality alteration has received considerable attention in urban streams (Paul and Meyer 2001). However, data from all but the most highly urbanized catchments in the Pacific Northwest suggest no clear relationships between a broad suite of conventional water-chemical parameters and biological health (May et al. 1997, Horner and May 1999). Increases in conductivity and nutrients commonly are associated with increases in urbanization (May et al. 1997, Herlihy et al. 1998, Walsh et al. 2005a) but corresponding ecological effects are relatively weak, closely correlated with hydrologic responses, and generally cannot be explained solely in relation to chemical water-quality standards.

The purpose of my paper is to review past and ongoing studies in terms of 1) assessing the prevalence and importance of hydrologic alteration in urban catchments, and 2) evaluating the nature and outcome of common enhancement approaches in urban streams. In combination, these studies suggest a framework for approaching urban stream restoration, in particular one that recognizes not only the importance of the hydrologic regime but also the unique constraints of the urban environment on achievable goals and objectives for restoration.

Sources of Data

Relationships between urban land cover, biological condition, and hydrology are evident in several studies across the Puget Lowland (see Booth et al. 2004), with data collected from 45 sites on 16 second- and third-order streams in King and Snohomish counties. Streams have similar catchment areas (5–69 km^2), local channel gradients (0.4–3.2%), soils, elevation, and climate typical of the central Puget Lowland, and urban development as the dominant human activity (American Forests 1998). Total imperviousness (TI, the % of a catchment covered by impervious surfaces) was used to characterize degree of urban development in the catchments draining to each site; TI values were determined from a classified 1998 Landsat image (30-m resolution; Hill et al. 2003). Paved land cover in the contributing catchments ranged from near 0 to almost ⅔.

Benthic macroinvertebrate assemblages were sampled at all 45 sites from 1997 to 1999 (Morley and Karr 2002). The biological condition of each site was quantified by the 10-metric benthic index of biotic integrity (B-IBI, Karr 1998), which includes measures of taxon richness, tolerance to disturbance, and selected ecological attributes (e.g., proportion of clingers and predators). Hydrologic analyses were conducted at all of the macroinvertebrate sites that were close to gauging stations and without intervening input of tributaries ($n = 18$ total sites; Konrad 2000). Equivalent hydrologic analyses also were conducted for 10 additional lowland streams with similar gradients and catchment geology, but some with catchment areas up to 171 km^2, to allow a more thorough assessment of the influence of contrasting catchment urbanization on flow regime.

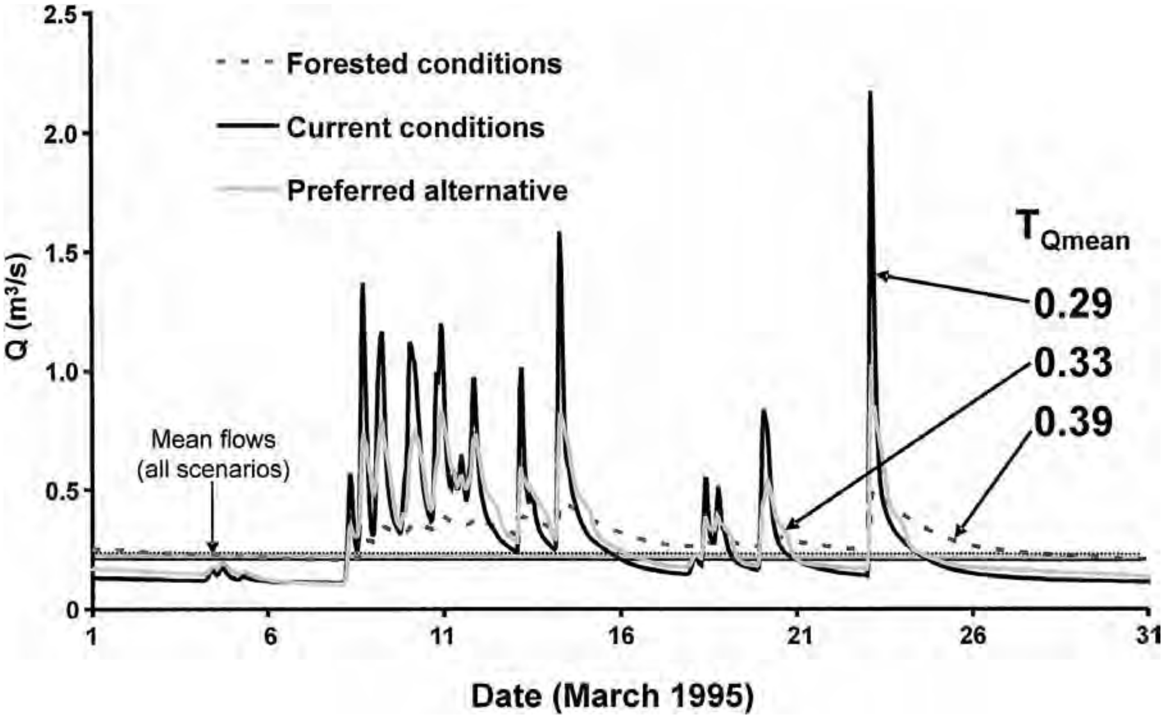

FIG. 2. Example of variation in the fraction of a year daily mean discharge exceeds annual mean discharge (T_{Qmean}) as a result of urban development, displayed with simulated hydrographs for Des Moines Creek in the central Puget Lowland (lat ~47°24′N, long 122°20′W). Hydrographs and corresponding values of T_{Qmean} compare predevelopment (forested) condition for this 14-km^2 catchment, current (degraded) condition, and full catchment urbanization with a hypothetical detention pond and high-flow bypass pipeline (preferred alternative; estimated cost = $8 million US). Simulation results courtesy of King County Department of Natural Resources (King County 1997). Note that traditional hydrologic mitigation (i.e., preferred alternative) effectively reduces flood peaks, but its influence on T_{Qmean} values is significantly less pronounced.

Quantifying Hydrologic Alteration

Changing flow patterns over time scales of months to years potentially imposes a long-term regime of frequent disturbances to stream biota (e.g., Pickett and White 1985, Poff et al. 1997). In contrast, the long-term ecological consequences of a single 1- or 2-d flood are likely to be unimportant because episodic high flows are part of most riverine systems, irrespective of human disturbance. Published hydrologic statistics that represent long-term storm and baseflow patterns relevant to stream biota include baseflow stability, daily discharge variability, and spate frequency (Poff and Allan 1995); the ratio of flood-to-baseflow volume, the frequency of high flows, and the product of frequency and duration of high flows (Clausen and Biggs 1997); and the fraction of a year daily mean discharge exceeds annual mean discharge (T_{Qmean}) (Konrad and Booth 2002, Konrad et al. 2005).

T_{Qmean} provides an intuitive index of urban influence on flow regimes because it reflects the annual or decadal distribution of runoff between storm flow and base flow. As such, it reflects the degree of flashiness in a stream hydrograph (Fig. 2). T_{Qmean} is expected to decrease with urban development because annual mean discharge changes little in response to urbanization, whereas duration of individual flood peaks shortens greatly (Konrad and Booth 2005). This metric was used to characterize hydrologic conditions in the study catchments because of its demonstrated responsiveness to urbanization.

The correlation of biological conditions (as B-IBI) with T_{Qmean} in the Puget Lowland study sites was about as good as with TI ($R^2 = 0.67$ for B-IBI vs T_{Qmean}, $R^2 = 0.70$ for B-IBI vs TI, both $p < 0.001$; Booth et al. 2004). However, T_{Qmean} is a more useful parameter than TI for understanding degradation processes because it more closely represents a likely causal mechanism for stream degradation. T_{Qmean} is not a gross measure of human disturbance, but instead expresses a disturbance signal for a specific environmental feature (e.g., Roy et al. 2003). Urban stream degradation has multiple causes, but the consistency of the B-IBI–T_{Qmean} relationship coupled with the ubiquity of hydrologic alteration in urban and urbanizing catchments (Booth and Jackson 1997) suggest that hydrologic alteration is a fundamental determinant of biotic changes in these systems.

Historical Approaches to Restoring and Rehabilitating Urban Streams

Goals for stream enhancement projects vary both spatially and temporally. They are sometimes articulated in terms of restoration, namely the return to predisturbance conditions (Cairns 1989). More typically, however, such goals offer only the more modest objective of rehabilitation, the measurable improvement of a limited number of elements, with the associated hope of some overall improvement in stream biological health. In either scenario, the focus is typically on the channel's physical condition, with little or no corresponding evaluation of the biological response. Yet, synoptic reviews and specific examples both demonstrate the inadequacy of physical enhancement approaches alone.

Bethel and Neal (2003) noted the following prevailing goals for stream-enhancement projects in the Puget Sound region: ''1. to establish the channel morphology appropriate to the topographic, geologic, and hydrologic setting, and 2. to establish the channel and riparian habitat that support a diverse native plant and animal community appropriate to the setting''. This perspective was affirmed by most stream-enhancement projects in the Puget Sound region during the 1990s (CUWRM 1998). Of the nearly 400 stream-enhancement projects reviewed in CUWRM (1998), 90% fell into 4 broad categories involving physical rehabilitation: riparian enhancement (planting and fencing; 35% of all projects), instream habitat augmentation (large woody debris [LWD] installation, gravel placement, and large rocks; 22%), bank stabilization and grade control (18%), and fish passage enhancement (15%). Each of these project categories typically affects only a few tens to, at most, hundreds of meters of stream channel. The CUWRM (1998) study also reported very limited construction of flow-control projects such as regional detention ponds, presumably because of their high financial and environmental cost (e.g., King County 1994) and dubious effectiveness in hydrologic restoration (Booth and Jackson 1997). In this context, Fig. 2 is an example of how very high project cost results in only modest hydrologic improvement. More integrative and potentially more effective flow-control strategies, notably low-impact development (LID; USEPA 2000) or the disconnection of impervious surfaces from the stream network (Walsh 2004, Walsh et al. 2005a), are poorly represented by projects during this period (CUWRM 1998), although implementation is now becoming more widespread (e.g., Puget Sound Action Team 2003).

Despite the high abundance of stream-enhancement projects, reported evaluations are remarkably limited, and available monitoring results are not very encouraging (Beschta et al. 1994, Kondolf and Micheli 1995). For example, Frissell and Nawa (1992) evaluated rates and causes of physical impairment or failure for 161 fish-habitat structures in 15 streams in southwest Oregon and southwest Washington. Their study catchments generally had been affected more by logging rather than by urbanization, yet despite this generally less severe form of catchment disturbance, functional impairment and outright project failure was common (median damage rate = 60% following a single flood, with a 2- to 10-y recurrence interval; Frissell and Nawa 1992). In particular, Frissell and Nawa (1992) found that damage to restoration projects was most widespread in streams with signs of recent catchment disturbance, high sediment loads, and unstable channels. They argued that restoration of alluvial streams with the greatest potential for fish production in the Pacific Northwest requires reestablishment of natural catchment and riparian processes rather than the construction of instream features. Larson et al. (2001) reviewed 6 projects in which LWD was placed into small suburban and urban streams and reported that these projects produced, at best, only modest changes in channel structure but generally no improvement in biological condition. Hession et al. (2003) reported that urban stream reaches with forested riparian corridors in Pennsylvania and Delaware displayed differences in a few benthic macroinvertebrate metrics compared with nonforested sites, but only at the lowest levels of catchment TI. The common theme of these and other stream-restoration projects is their narrow symptomatic focus (e.g., bank erosion or lack of pools or LWD at a site) in response to an underlying disturbance at a much larger, typically catchment scale (e.g., logging or urbanization).

Anecdotal examples graphically demonstrate the challenges involved in restoring streams using only symptomatic, local-scale approaches. Madsen Creek drains 6 km^2 of largely urban and suburban upland plateau in the Puget Lowland, ~20 km southeast of Seattle. In 1989, the lowermost kilometer of the channel was relocated as part of a road-widening and fish-enhancement project designed to recreate salmon-spawning habitat. The stated project objective was simply to deploy the specified quantities of logs, stumps, riparian plants, and streambed gravel to the site. Logs and rootwads were placed in the channel, gravel of a size deemed suitable for salmon spawning was spread over the bed, and fast-growing native riparian species were planted along the banks (Fig. 3A). A large rainstorm that winter created significant flooding and erosion in the stream, and erosion of a steep ravine below the upland deposited hundreds of m^3 of sand and silt throughout the project reach that destroyed most of the constructed habitat elements (Fig. 3B). Eight years of relatively benign flows later, the channel offers an instructive case both for and against site-scale rehabilitation (Fig. 3C): the riparian corridor is healthy and provides shade, litter, and protection to the stream, but the large manmade structures are either buried or eroded, and the channel bed remains sandy, ill-suited for salmon spawning, and reflects the sediment load of the upper catchment under present flow and erosion conditions. The project achieved only a subset of its goals, but not necessarily those of greatest concern or those that required the most costly actions.

Longfellow Creek, draining a heavily urbanized catchment in Seattle, provides another example of a local-scale action motivated by broad ecological goals but, at best, showing only marginal success. In- and nearstream projects to date on a 2-km reach include removing fish-migration barriers, planting riparian vegetation, reconstructing the channel, addition of spawning gravel, and placement of instream LWD (Fig. 4), for a cost of $8 million US. Post-restoration biotic conditions, however, have yielded massive pre-spawning death of returning (or stray) coho salmon (Seattle Post-Intelligencer 2003), with only a small fraction of salmon surviving long enough to spawn, and with virtually no smolt production (Fig. 5).

Consequences for Urban Stream Restoration

Habitat elements and habitat-building processes

The lessons of Madsen and Longfellow creeks and elsewhere are clear and should not be surprising. Certain instream conditions are easier to improve than others, but local actions cannot reverse the consequences of broadly degraded urban catchments. Given the financial and technological obstacles to fixing catchment-scale degradation, particularly hydrologic alteration, urbanization often promotes the inescapable consequence of limiting efficacy of local-scale actions (Barker et al. 1991, Booth and Jackson 1997, Maxted and Shaver 1999, Booth et al. 2002, Morgan and Cushman 2005).

The difficulty in managing multiple scales of degradation has long been explored in forestry-dominated landscapes, where the distinction between aquatic-habitat ''elements'' and habitat-building ''processes'' usefully discriminates the construction of channel features from the establishment of self-sustaining improvements (Cederholm et al. 1997, Roni et al. 2002). For example, fish habitat in Pacific Northwest streams includes such elements as LWD, pools, riparian and instream cover, gravel deposits, floodplains, and riparian vegetation. Each of these habitat elements can be built on-site, but neither their longevity (Frissell and Nawa 1992) nor their biological effectiveness (Larson et al. 2001) can be documented. Roni and Quinn (2001) noted that streams subject to outmoded forest practices and with initially low amounts of instream wood generally showed the most dramatic increases in habitat quality and fish abundance following local-scale LWD introductions. This outcome is logical for channels where the absence of LWD occurred primarily by physical removal (e.g., Collins et al. 2003). Yet, catchment processes that create and must permanently support such features (i.e., forest succession, sediment input, flow regime, geomorphic evolution of alluvial channels) operate at such broad

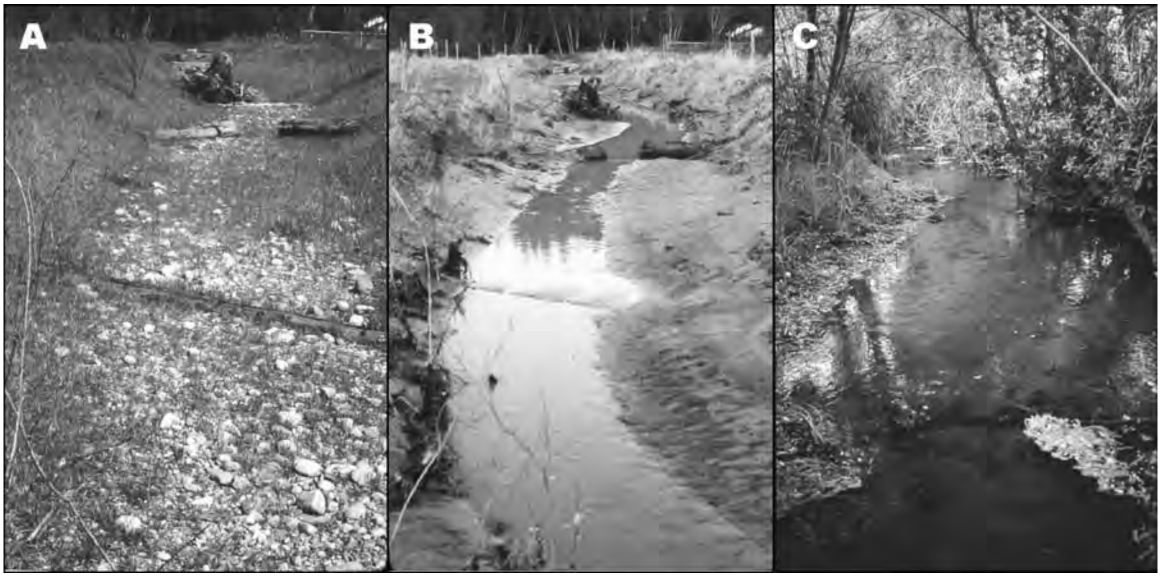

FIG. 3. Reconstruction, disturbance, and partial recovery of lower Madsen Creek, southeast of Seattle, Washington. Photographs taken September 1989 (A), February 1990 (B), and April 1998 (C).

FIG. 4. Longfellow Creek, in the city of Seattle, Washington, shortly after channel reconstruction with log deflectors, imported channel-bed sediment, and riparian plantings.

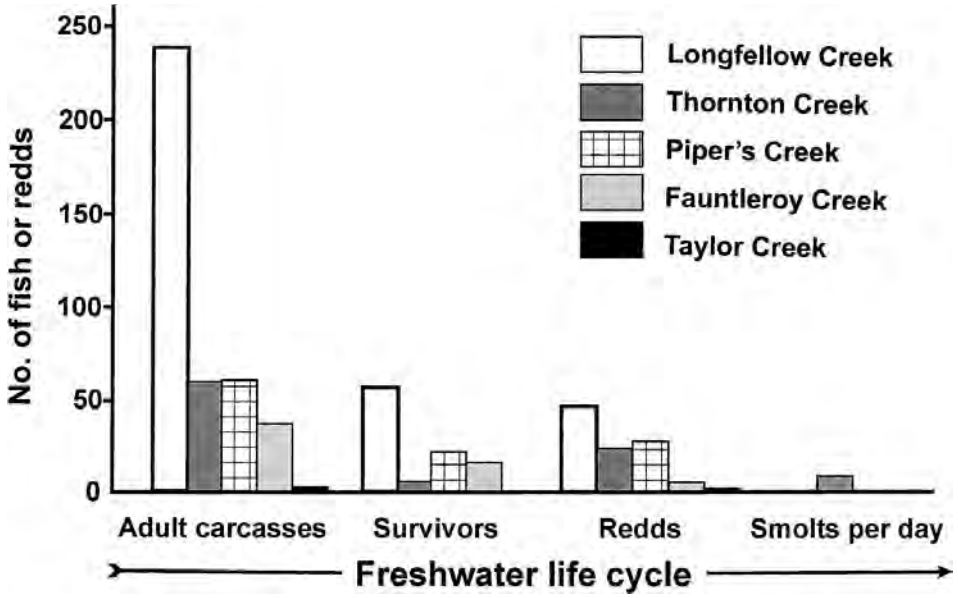

FIG. 5. Decline in survival at successive life stages of coho salmon in the 5 major streams of Seattle, Washington (2003 data from the City of Seattle).

spatial and temporal scales that their products will not persist if simply built or replaced (Kauffman et al. 1997, Roper et al. 1997, Beechie and Bolton 1999, Kondolf et al. 2001), particularly in flashy, unstable urban systems.

Short- and long-term enhancement of urban streams

This distinction between habitat elements and habitat-building processes suggests an alternative perspective to urban stream enhancement: short- vs long-term restoration activities. The former actions are generally feasible under many different management settings but unlikely to produce permanent effects; they include riparian fencing and planting, water-chemistry source control, fish-passage projects, use of instream structures, and construction of social amenities. Short-term actions address acute problems typical to stream channels in urban and urbanizing catchments (Miltner et al. 2004) and so are normally worthwhile, although they only provide immediate solutions that are necessary yet are insufficient to restore biotic integrity.

Short-term actions also must acknowledge the presence of people in urban environments. Actions enhancing the quality of interactions between people and urban streams, particularly those justified in terms of quality of life or by their value as a public amenity, are likely to be supported and maintained; indeed, such actions commonly result in financial outlays far in excess of likely ecosystem benefits (Middleton 2001). Conversely, actions degrading or limiting interactions between surrounding human communities and streams are more likely to fail. This situation is particularly relevant for short-term actions because they often are unlinked to catchment processes and so typically require continued maintenance to achieve even their transitory objectives. Use of public education to guide community actions in maintaining sustainable and ecologically beneficial streams and stream-enhancement projects is sorely needed (Purcell et al. 2002), which is a particular urgency in the Pacific Northwest because most urban streams flow across private property and thus lie beyond the jurisdiction of public agencies (Schauman 2000).

In contrast, long-term actions are, by definition, self-sustaining, and they address catchment processes at their relevant scales. However, they also must address each potentially degraded environmental feature (Fig. 1) if they are to achieve enhanced biological health. Examples include landuse planning such as preserves or zoning (King County 1994), avoiding road- and utility-stream crossings (Avolio 2003), rehabilitating upland hydrology (e.g., stormwater rein-

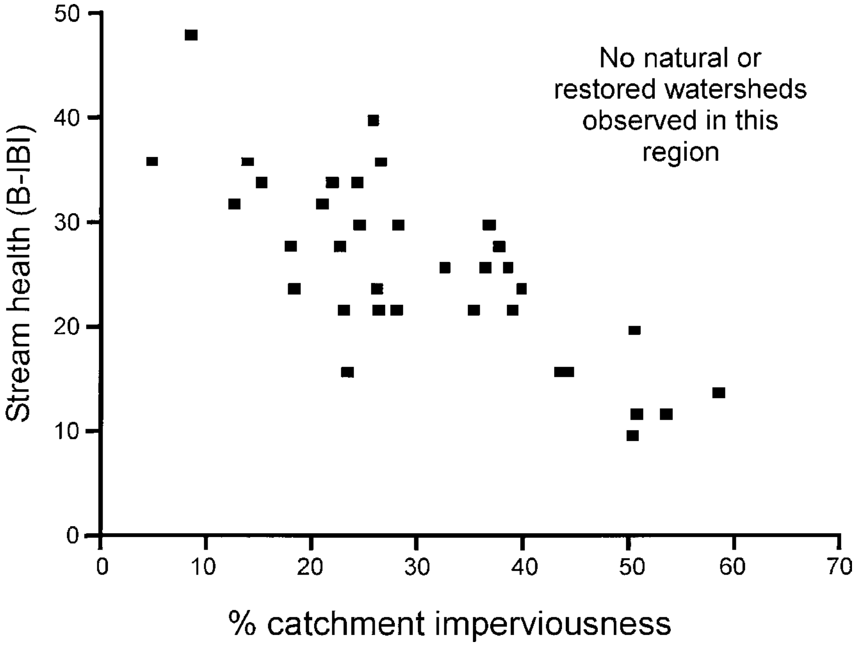

FIG. 6. Percent catchment imperviousness plotted against stream health (as benthic index of biotic integrity [B-IBI]) for Puget Lowland stream data. Management goals are commonly articulated for the upper right-hand corner of this graph (i.e., high-quality streams in highly urbanized watersheds), although no evidence suggests that this condition exists (modified from Booth et al. 2004; B-IBI data from Morley and Karr 2002).

filtration or LID; Walsh et al. 2005a), establishing riparian-zone vegetation communities, and reconnecting floodplains with their channels (Buffington et al. 2003).

Stewardship by the surrounding human community is as important with long-term as with short-term actions; however, it must emphasize instream biotic health over direct human interaction with stream channels (Schauman and Salisbury 1998). A long-term focus on enhancement, therefore, tends to exclude people from stream and riparian environments, even though enhancement requires social support to ensure ecological success. There are few examples or case histories to guide the development of this task.

Despite good intentions, strong public interest, and massive funds, we have virtually no examples of having achieved or retained biotic integrity—i.e., ecological health akin to that in undisturbed streams—in degraded urban channels. An example of this pattern comes from streams in the Puget Lowland (Morley and Karr 2002), where catchment imperviousness plotted against stream health (as B-IBI) showed no high-quality streams in highly urbanized catchments (Fig. 6). Clearly, we have not yet developed nor implemented a truly effective stream-enhancement strategy, a failure that echoes a long-recognized conclusion in ecological restoration regarding the challenge of achieving predisturbance ecosystem conditions in human-modified landscapes (Cairns 1989).

Towards better urban streams

The above perspective raises 2 key management questions for degraded urban catchments. First, can a natural flow regime ever be reestablished in an urban catchment and, if so, how? Second, if such a flow regime *cannot* be reestablished in urban catchments, what outcomes might be expected from other management actions that either construct short-term elements or reestablish some long-term processes (e.g., water-quality treatment, improved instream habitat, replanted riparian zone), but that do not address reestablishment of a natural flow regime?

A retrospective view suggests that the answer to the 1st management question is *no,* but failure of the last century's management of hydrologic alteration should not condemn us to the same future. Instead, it merely emphasizes the need for new approaches to stormwater management, preferably those integrating multiple scales of catchment planning, site layout, and infrastructure design. Such efforts are now beginning throughout the world (e.g., Puget Sound Action Team 2003, Walsh et al. 2005a), although their effectiveness is yet to be demonstrated. Determining the optimal combination and resulting effectiveness of such stormwater-management strategies should be a priority because their promise is great, alternatives are lacking, and confirmatory data for design guidance are presently sparse.

Yet full, or at least partial, long-term restoration of some habitat-forming processes, with subsequent biological recovery, may be possible even in highly disturbed urban environments. Such restorative actions include controlling of landslides and surface erosion to minimize changes to sediment-delivery processes, protecting mature riparian buffers to maintain delivery of coarse and fine organic debris and to moderate solar input (Jones et al. 1999, Parkyn et al. 2003), and disconnecting the pipes linking impervious areas to natural channels (Walsh et al. 2004, 2005a, b). For example, a B-IBI increase from ''very poor'' to ''fair'' over <2 km along a single suburban Puget Lowland stream channel was strongly explained by riparian land cover but not by overall catchment land cover (Morley and Karr 2002). Avolio (2003) and McBride and Booth (2005) have documented good correlations between physical condition of channels and frequency of stream-road crossings. Such results point to actions that are generally sensible to implement, even under existing management constraints, because they are often economically feasible and may provide long-term benefits. Furthermore, the absence of abrupt thresholds in biological responses to urbanization (e.g., Booth et al. 2002, Morley and Karr 2002) suggests that even incremental improvements can have direct, albeit commensurately modest, ecological benefits.

In the absence of effective hydrologic mitigation, however, what are appropriate objectives for urban streams (e.g., see also Osborne et al. 1993)? Point sources of pollution should be eliminated. In addition, channels should have the same physical elements (e.g., pools, substrate, logs, accessible floodplains) as their equivalent undisturbed counterparts, with the recognition that these elements are necessary but not sufficient to support future biotic improvements. Urban streams also should be considered neighborhood amenities that inspire passion and ownership from their nearby residents, and they can be self-sustaining to biotic communities, even though those communities depart significantly from predisturbance conditions.

Last, urban streams should also retain the possibility, however remote, of one day benefiting from the long-term actions that can produce greater, sustainable improvements. This final goal cannot be achieved for most urbanized catchments under present socioeconomic constructs, at least not in the Pacific Northwest. This constraint should be a reminder not to spend large sums of money on targets that can never be reached by paths that are all-too-commonly followed. This excuse is not sufficient, however, to continue building the kinds of urban developments or traditional rehabilitation projects that permanently preclude future long-term stream improvements.

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About the Author

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Board Workshop
Bio Objectives
Deadline: 2/25/13 by 12 noon

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February 25, 2013

Ms. Jeanine Townsend
Clerk to the Board
State Water Resources Control Board
1001 I Street, 15th Floor
Sacramento, CA 95814

SUBJECT: **<u>Comment Letter – Board Workshop: Scientific Basis for Development of a Statewide Policy for Biological Objectives</u>**

Dear Ms. Townsend:

The California Association of Sanitation Agencies (CASA), Tri-TAC, the Southern California Alliance of Publicly Owned Treatment Works (SCAP) and the Central Valley Clean Water Association (CVCWA) appreciate the opportunity to provide written comments associated with the State Water Resources Control Board's (State Water Board's) Workshop: Scientific Basis for Development of a Statewide Policy for Biological Objectives. Our associations collectively represent public wastewater agencies that provide sewer collection, wastewater treatment and water recycling services to millions of Californians. Our membership safely reclaims more than two billion gallons of wastewater each day.

First and foremost, our associations commend and appreciate State Water Board staff for the open and inclusive stakeholder process and communications incorporated in to the development of the scoring tools and causal assessment approaches. We hope and request that a similar process is utilized during development of the implementation and regulatory-related components of the Policy. We also appreciate staffs' commitment during the workshop to providing stakeholders with copies of any draft statewide policy for biological objectives (Policy) prior to it being sent out for peer review. Finally, we would also like to acknowledge and recognize the tremendous contributions made by the experts assembled by staff to serve on the Technical Team and Science Advisory Group (SAG). Their knowledge, expertise, and scientific input were instrumental in the development of the novel California Stream Condition Index (CSCI) scoring tool. Although the workshop represented the first public overview of this tool, it appears to be more robust and applicable than previously presented approaches and the more commonly utilized regional indices. We look forward to being able to provide more significant technical input once the details of this unique scoring tool have been released.

Even with the development of the seemingly more robust CSCI scoring tool, we suggest that the State Water Board proceed carefully with the implementation of this Policy and thoroughly consider the potential financial and resource impacts this Policy may have on the residents of California. Considering the significant limitations in the causal assessment tools and the potential financial, environmental, and social costs associated with this Policy, the State Water Board should avoid incorporation of any Policy-related implementation components that cannot reliably be expected to achieve reasonable beneficial use goals. Additionally, impacts to beneficial uses not typically recognized by the State Water Board should also be considered and carefully evaluated as staff moves forward with development of the implementation provisions. Examples that should be a part of this discussion include flow alterations associated with recycled water use and deliveries, as well as stream modifications associated with flood control. Many channels are constructed and/or altered to move and deliver recycled water or to protect life and property during flooding. This anthropogenic and necessary channel modification by itself is a stressor known to alter benthic macroinvertebrate populations, and if not carefully addressed, could be impacted as a result of this Policy.

Since formal documents are not available during this comment submission period, the following comments and perspectives are based on our understanding of Policy elements as presented in Stakeholder Advisory and SAG meetings as well as additional conversations with State Water Board staff and members of the Technical Team:

1. An evaluation of current causal assessment tools that included development and examination of new alternative tools by the Technical Team and stakeholders found that these tools were limited in their ability to identify specific causes impacting benthic macroinvertenbrates (BMIs), even in well monitored, “data rich” reaches, when the stressors influencing those reaches are believed to be chronic and systemic. Sound biological objectives in the absence of robust and reliable causal assessment tools have no value. BMIs are not “pollutants” and are known to respond to a wide range of natural and anthropogenic stressors, including stressors that the State Water Board is not willing and/or not authorized to control. Therefore, it is imperative that sound and robust causal assessment tools be developed that can reliably identify specific stressors impacting a stream. **We request that the State Water Board commit the necessary resources to retain the Technical Team and SAG to provide scientific input into development of sound causal assessment tools.**

2. It is anticipated that current funding commitments are expected to allow for the development of a “black box” California Environmental Data Exchange Network (CEDEN) module for processing bioassessment taxonomic data combined with latitude and longitude coordinates that will seamlessly calculate CSCI scores. However, conversations with members of the Technical Team have indicated that there is currently no funding available to develop, support, and maintain an FTP or other appropriate residence for the component tools including the reference database, R scripts, and other the tools that would allow capable individuals to perform and verify these calculations independently. Furthermore, development of the CEDEN tool is anticipated to take many months to complete. In the meantime, interested stakeholders will not have access to any scoring tools required to conduct their own evaluations. **We therefore request that the State Water Board provide the necessary efforts and funding to make the component tools available as soon as possible so that stakeholders (regulators, regulated, and NGOs) can start to effectively evaluate the scoring tool.**

3. Some stakeholders remain concerned that even with the recent addition of reference locations from underrepresented eco-regions, expectations for some streams (low slope, large watershed, unusual or unique geology, etc.) may not be appropriate. Members of the Technical Team have indicated that formal tests of applicability are possible with the new scoring tool, but these tests have not been developed. Furthermore, such an evaluation would require access to the

statewide data base and component tools. **In addition to providing stakeholder access to the component tools described above, we also request that the State Water Board utilize the Technical Team and SAG to develop formal applicability tools and assist in evaluating and providing input into these and other potential shortcomings**.

4. Scientific input is needed to evaluate whether or not “expectations” (however they are ultimately derived as a result of this Policy) can be reasonably achieved for streams. While it is anticipated that “expectations” for modified streams are likely to be different from those in undeveloped areas, technical insight is needed to determine if such “expectations” can be reliably achieved and if so, whether or not those “expectations” represent a significant improvement in the aquatic life beneficial use. **We therefore request that the State Water Board continue to retain and support the Technical Team and SAG during discussions on where objectives may be applied and what those objectives should be to provide the necessary technical guidance to help inform the regulatory applicability of the Policy.**

5. During the development of the observed over expected (O/E) component of the scoring tool, the SAG advised that rare species, those with less than a 50% probability of occurring at a site, should be excluded because including them increases the “noise” relative to the signal and results in decreased overall precision. However, with the modeled multi-metric index (MMI) component of the scoring tool, the complete taxa list (rare and common species) are utilized. A cursory observation of limited CSCI data indicates that the MMI component tends to score lower than the O/E component. While the two components scoring different is not unexpected, it would be concerning if one component typically scored less than the other. If such a bias exists, it may be a function of the increased signal to noise associated with incorporation of “rare” taxa into the MMI component. Since the CSCI is an average of the two scoring components, we are concerned that a systematic bias associated with increased “noise” in one component could ultimately result in an inaccurate assessment of the overall CSCI. For example, in some instances, the O/E component scored 1.5 (50% better than expected) which was then averaged with an MMI component score of 0.5 (50% lower than expected) resulting in a CSCI score 1.0 (100% of reference condition). In these cases, could the inclusion of rare taxa and associated increase in “noise” in the MMI component or the exclusion of rare taxa in the O/E component be confounding the overall assessment and are there techniques to address the apparent discrepancy? **We ask the State Water Board to request an evaluation by the Technical Team and SAG on this possible bias in the scoring tool.**

6. As this effort moves away from the development of the scoring tool and more into policy considerations associated with implementation, we strongly request that the State Water Board retain the Technical Team and SAG. Early on in the process, the SAG expressed an interest in knowing how the tool is likely to be implemented in a regulatory context in order to better help them more effectively provide input. This is particularly important in addressing and quantifying uncertainty. Significant uncertainty still exists regarding how and where the biological objectives identified in this Policy will be used in identifying impairment (303(d) listing), application of causal assessment tools, and associated management actions. Therefore, it will be necessary to reconvene these experts to assess whether or not the tool is robust and reliable enough to support potential regulatory actions in all areas the State Water Board ultimately intends to apply the Policy. For example, it is still unknown if the Policy will apply

reference expectations to all waters or if some eco-regions will be exempted entirely or whether alternative regulatory approaches, such degradation prevention or "best attainable" expectations could be ultimately selected. **It is our opinion that the Technical Team and SAG could provide significant technical input into where the tools are most reliable, where alternative approaches may be most useful, and what expectations are reasonable for specific habitat conditions, such as modified channels. We ask the State Water Board to actively utilize the Technical Team and SAG to provide such input.**

7. The SAG clearly indicated that the setting of CSCI impairment thresholds was purely a policy decision with no scientific or technical basis. For individual pollutants, impairment thresholds are set at a level with some clear connection to an aquatic life or human health effect. However, with biological objectives, the selection of an impairment threshold is an arbitrary decision based on an arbitrarily selected degree of allowable deviation from the "expected" reference condition, which is in itself highly uncertain (i.e. while all reference sites should be "expected" to score 1.0, actual CSCI scores at reference locations vary from about 0.3 to 1.4). While utilizing percentiles or standard deviations from a reference distribution provides some level of mathematical objectivity, the setting of an impairment threshold still ultimately comes down to a simple choice with no biological or ecological significance. For example, if the State Water Board would prefer to have more streams identified as "impaired", they can simply set the threshold at one standard deviation from reference condition. If they would like to have fewer streams identified as "impaired", they could set the threshold at three or four standard deviations from reference condition. Conversely, the setting of a biological impairment threshold could be determined by deciding how many non-impaired reference streams the State Water Board is willing to incorrectly identify as "impaired". If it is desirable to identify very few reference streams as "impaired", then the State Board could set the threshold at three or four standard deviations from reference expectations. If it is more beneficial to increase sensitivity at the expense of identifying a significantly high number of reference streams as "impaired", then they could alternatively set the threshold at one standard deviation from reference condition. **We recommend that the State Water Board consider using the percentile or standard deviation approach as a means of prioritizing streams and reserve the identification of "altered" or "impaired" to only those locations falling below the lowest CSCI score observed in the reference pool. This would prevent identifying any reference stream as impaired and identify (and prioritize) the most significantly impacted streams.** Streams scoring above this threshold, but below one standard deviation of reference condition could be categorized as being on a "watch list". If additional categories are desired, they can easily be accommodated by using intermediate thresholds.

8. Natural disturbances such as fire, decreased and increased flows associated with drought and storm events, and even large scale climate changes have been documented or suspected to have extremely large, and in some cases long lasting impacts on biological condition. By using a ten-year indexing period when selecting reference locations, some of these disturbances may have been incorporated to some degree into the setting of reference condition and may actually partially explain why the range of CSCI scores in reference streams is so large (CSCI scores ranging from about 0.3 to 1.4). However, there has been no detailed discussion on how to account for these expected, natural changes in biological condition observed at a test site using data collected over a much shorter time period. Even more frequent and localized natural

changes such as those associated with the annual variations in precipitation appear to not have been adequately addressed. In development of the tool, precipitation as a long-term average (10-year average precipitation) was incorporated, but was not a determined to be a significant driver of expected biological condition. However, more short-term and natural annual drought and flooding events were not evaluated. While the long-term (10-year) average precipitation is relatively constant, inter-annual precipitation across much of the state is best characterized as a multiyear cycle of widely fluctuating precipitation rates. For example, in southern California, 61 out of the previous 133 years exhibited annual rainfall rates that differed from the long-term average by over 30%, and a cursory review of precipitation patterns for San Francisco and San Diego revealed a similar pattern. Since it is well documented that short-term scouring events associated with significant storm events can have a substantial impact on benthic macroinvertebrates, it is critical that the community changes associated with natural stressors be documented and addressed in either the scoring tool, the implementation approaches, or both. **We request that the variability of the CSCI associated with natural disturbances, particularly with inter-annual fluctuations in rainfall associated scouring event, be evaluated.**

9. In response to Board Members' questions at the Workshop and in discussions at the Stakeholder Group meetings, the Technical Team clearly indicated that a fish community index to evaluate biological condition would be infeasible in California. California has relatively few remaining native fish species and the majority of streams and lakes in the State are dominated by introduced non-native species, many of which provide significant angling recreational benefits. The State Water Board lacks the ability to eradicate the dominant non-native fish species in the State such as largemouth bass, catfish, bluegill, and brown trout. This list only represents a fraction of the non-native fish species that may be creating barriers and making restoration of fish communities impossible. Moreover, any such attempt at doing so would be perceived as extremely unpopular with the recreating public and other state agencies. Therefore, development of a native fish index has not been pursued in favor of the benthic macroinvertebrate and algal community indices with the understanding that the fish communities in nearly all of California's streams will always be biologically "poor". For this reason, if the intent of this Policy is to restore the biological condition of California's streams, it will fail in nearly all instances, even if invertebrate communities achieve a high level of ecological function. **In recognition of this ecological limitation, the State Water Board should more clearly and directly identify the specific intent and goal of this Policy so that a Policy can be drafted that will be likely to achieve those goals.**

10. During the January workshop, the Executive Officer of the San Diego Regional Water Board indicated in his presentation that this Policy is greatly needed in his region as a tool that will help in prioritizing streams in the region. Coincidently, a stakeholder group member also testified at that workshop that they were supportive of development of this Policy as a valid and workable tool for prioritizing streams. Considering that this Policy, and in particular the scoring and eventual causal assessment tools incorporated into this Policy, represent a novel approach for addressing biological condition, the State Water Board should carefully consider how it is implemented. For some, the most significant emphasis should be in identifying those streams that are those currently scoring extremely high to help prioritize management actions to protect the resource. Others desire a tool that is capable of identifying streams marginally different

from reference to aid in supporting management actions most likely to result in a tangible improvement in beneficial uses. However, if the Policy ultimately sets a numeric target to assess a narrative Basin Plan Objective, the Policy will fall short of Regional Water Boards' and other's expectations that this will serve as a tool to effectively assist them in prioritizing streams. Instead of being able to allocate resources where they can be most effective or most needed, the Clean Water Act would obligate that all streams not meeting the arbitrary threshold would need to be addressed. This would result in resources being unnecessarily spread out across all streams failing the arbitrary threshold, with no leeway to focus efforts and resources on priority streams. **<u>We therefore recommend that the State Water Board pursue a Policy approach that utilizes the technical tools to prioritize streams instead of using it to make formal impairment decisions under the Clean Water Act.</u>**

11. In keeping with pursuing a prioritization approach, consideration should also be given to phasing implementation of the Policy. Under such a phased approach, the initial use of the Policy would be to incorporate monitoring and scoring with the new tools followed by establishment of priority classifications. Presumably, initial management priorities would be limited to the highest scoring streams in which reference conditions are attained. These streams potentially represent vulnerable and ecologically important areas and are the areas where existing causal assessment tools and corrective actions are most likely to be successful. In later phases, the Policy could be better developed using information learned from earlier phases including the effectiveness of management practices, reliability of achieving the desired biological condition, costs and other insights with the intent to eventually expand usage to other regions and areas. This will initially restrict use of the objectives and causal assessment tools to areas where there is little disagreement as to their applicability and where successful causal identifications are most likely to be obtained. Subsequent phases to extend applicability where appropriate can then be considered and developed utilizing the lessons learned and new tools developed during the previous phases as more information on the appropriateness of applying biological objectives to these areas is obtained.

12. State Water Board staff and the technical experts correctly assert that poor habitat condition is the likely cause of many if not most of the biological impairments in California, particularly in areas with significant urban and/or agricultural development. In southern California and elsewhere in the State, many perennial and wadeable streams are channelized. Such channel modifications greatly impact reasonable biological expectations. Setting reference expectations based on minimally impacted land use conditions for these modified habitats is generally accepted as being unreasonable, but setting some alternative intermediate expectation other than reference condition would also be unsupportable biologically and functionally arbitrary, unless beneficial use designations are also modified to reflect actual habitat conditions.

    It is important that the State Water Board carefully consider the reason that these streams have been so heavily modified. For example, in the Los Angeles Region, the Los Angeles River historically meandered year to year between ocean outlets on Santa Monica Bay (Ballona Creek) and San Pedro Bay. It was also common for the San Gabriel River during high flow periods to actually join with the Los Angeles River. However, after disastrous floods in 1914, 1934, and 1938 that killed more than 100 residents and destroyed 5,600 homes, these rivers were channelized and headwaters dammed to protect people and property. Since that time, significant stretches of land along these rivers have been developed and currently support safe housing and industry, protecting hundreds of thousands of people in the region. Even now, these channels run full during large storm events while still protecting the community from flooding. Reasonably foreseeable control measures to improve biological condition in these channels include potential addition of cobble substrate, removal of armoring, and planting of vegetation. However, such measures will also decrease the capacity and capability of these structures to provide adequate flood control protection. Therefore, these controls could be expected to have drastic and possibly tragic impacts on housing, roads, industry, recreation, other vital infrastructure and the economies that rely on these services due to the expected decrease in flood control capacity. **Therefore, the State Water Board should carefully evaluate the efficacy of setting biological objectives that may result in the need to alter or to reduce capacity of modified channels providing vital and necessary public services such as flood control, water supply, agricultural drainage, and other critical services.**

13. Statewide biological objectives could have the unintended, but reasonably foreseeable consequence of limiting growth and expansion of recycled water projects through restrictions on the ability to obtain necessary permits for new or expanded projects or through the "artificial" establishment of a perennial stream subject to the provisions in the Policy where they did not previously exist. Clearly, the potential impacts associated with decreasing and increasing flows on macroinvertebrates have the potential to be significant, but have been largely unstudied. Water agencies are currently looking into new and potentially large groundwater recharge projects in a continuing effort to provide safe and reliable water for the State, and many POTWs are looking to expand recycled water uses in and near their communities. Such projects can be expected to reduce recycled water discharges into some stream reaches, while potentially increasing discharges in others due to the use of existing stream channels to transfer water to recharge and recycling projects. Uncertainty associated with potential macroinvertebrate impacts due to such water movements could lead to delays or even abandonment of these vital projects.

    To compound these issues, current and future water conservation efforts have and will continue to result in over-all decreases in POTW discharges, which will reduce flows into streams. Uncertainty over potential impacts on the macroinvertebrate community, particularly in areas with extensive stream channel modifications already in place, should not impede water conservation efforts. Impacts to water supply and water delivery will have significant and far ranging consequences throughout the state. Limitations and/or restrictions on water recycling and recycled water movement as a result of biological objectives would place increased demands on current water supplies, which are already under significant stress due to the dependence in much of the State on imported water supplies and the growing impacts of climate change. This could have drastic effects on California's $36.2 billion a year agricultural industry as the cost of water increases and more limited and less reliable water resources are diverted away from farming. This will result in increased food prices in California and across the nation as California provides over one half of the fruit and vegetable crops in the U.S. Such restrictions will also limit housing, industrial, and economic growth. Increased water recycling will allow for more sustainable residential and industrial development, but restrictions in response to uncertainty in meeting biological objectives could limit these opportunities. **Therefore, the State Water Board should carefully evaluate the efficacy of setting**

biological objectives that may result in restricting recycled water projects, expansion of existing recycled water programs, and the ability to utilize channels and streams for delivery of recycled water.

14. State Water Board staff recognize that reference biological expectations for some perennial and wadeable streams are not reasonable and have proposed alternatives that would establish an intermediate biological threshold lower than that of reference condition ("best attainable") for these streams. This approach functionally "tiers" the biological expectation to some lower level even though the designated aquatic life beneficial use for the stream may remain the same as those in a more pristine or reference state. We believe that a more systematic approach that would ensure that beneficial uses and water quality objectives are appropriately matched is to create additional subcategories of the aquatic life use and apply them as appropriate within each region, similar to an approach that has been successfully incorporated into Ohio's regulatory program that uses "tiered aquatic life uses" (TALU). In Ohio, the biological expectation has been adjusted up or down based on what is minimally necessary to support the tiered beneficial aquatic life use, recognizing that not all streams and channels should be expected to support the same beneficial use. Another approach would be to include a subcategory such as "Limited Warm Freshwater Habitat," defined by the Santa Ana Regional Water Quality Control Board to be waters "which support warmwater ecosystems which are severely limited in diversity and abundance as the result of concrete-lined watercourses and low, shallow dry weather flows which result in extreme temperature, pH, and/or dissolved oxygen conditions. Naturally reproducing finfish populations are not expected to occur in Limited Warm Freshwater Habitat Waters." (Santa Ana Region Basin Plan, Chapter 3, p. 4) State Water Board staff are proposing to tier/reduce the biological expectation knowing that meeting such an expectation will still not support the highest level of the desired beneficial use (or meet the narrative biological objective) because the beneficial use will remain unchanged. Therefore, the "best attainable" threshold becomes an arbitrary target that will not result in attainment of the biological objective and may or may not be necessary to support the desired aquatic life beneficial use. **For these reasons, it is imperative that the State Water Board evaluate an alternative that includes modifying both beneficial uses and water quality objectives to match those uses.**

15. There have been many discussions regarding how and where this Policy may apply. Some are expecting a tool that will help prioritize streams for more focused management actions. Others are interested in using the Policy to prevent biological condition degradation in currently high scoring streams, while still others anticipate that the Policy will result in regulatory mandated restoration of impacted streams. While we appreciate the opportunity to comment on the draft Policy before submittal to peer review, it would be helpful if the State Water Board could prepare and distribute a preliminary "straw man" outline of the regulatory and implementation components including where and how this policy is expected to be implemented well in advance of the preparation of the draft Policy. This will allow stakeholders including regulators, the regulated community, the Technical Team, SAG experts, and others to provide early input and identify potential technical limitations based on intended regulatory uses.

Our associations thank the State Water Board for this opportunity to provide input into the development of the Policy. We look forward to working with the State Water Board as it continues to develop statewide biological objectives. If you have any questions about these comments or require additional information, please contact Roberta Larson at (916) 446-0388 or blarson@casaweb.org.

Sincerely,

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