Layer-wise Application of River Habitat Enhancement Features Yields Significant Ecological Functionality and Physical Sustainability

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Abstract

Physical habitat losses for Pacific salmonids in California's Central Valley motivate stream restoration. Considerable river morphodynamics affect the sustainability of habitat enhancing interventions. In addition, the presence of large dams in many river catchments causes low sediment supply. This study revises existing stream restoration techniques for their ecologically efficient and physically stable embedding in a 36-km testbed river. Ecological efficiency is evaluated in terms of a commonly used hydraulic habitat suitability index. Physical stability results from 2D hydrodynamic modelling of bed shear stress during steady flows of different flood frequencies. We differentiate between terraforming, stabilizing and maintaining stream restoration techniques, which constitute three feature layers. The first layer, terraforming, includes artificial terrain modifications such as grading or backwater creation to generate new habitat. These features require stabilization, which is provided by the second feature layer. The stabilization (layer two) is achieved by bioengineering such as placement of streamwood, angular boulders and vegetation plantings. The third feature layer has the purpose to maintain newly created habitat, e.g., through artificial gravel injections. We illustrate the application of the three-layer-approach at one major restoration site of the lower Yuba River using a self-written Python package. Ecohydraulic 2D modeling was applied to designs with incremental layer additions to evaluate newly created spawning habitat and feature sustainability. This procedure represents a pertinent way for stream restoration planning, which avoids non-sustainable habitat enhancement features and implements ecologically as well as physically sustainable features only.

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Introduction

Stream restoration practice

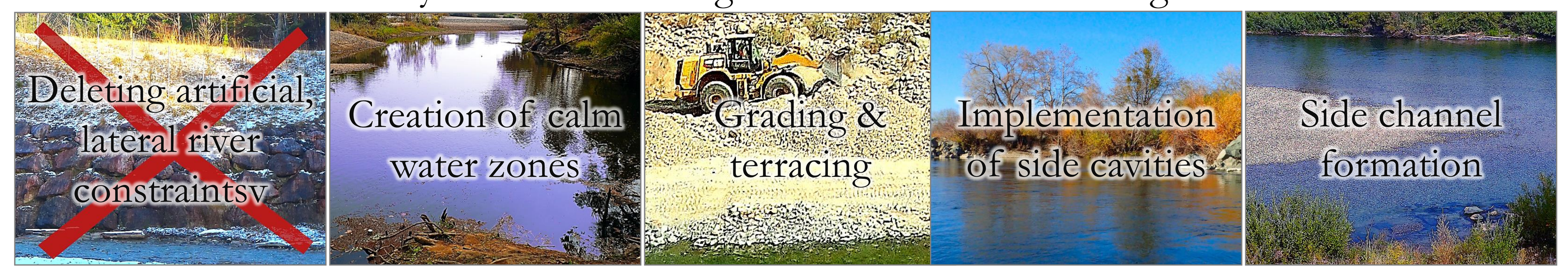
- Rivers experience anthropological impacts: withdrawals, gold mining, or agriculture.
- Many stream modifications caused morphological, ecological, and hydrological alteration, which resulted in declining habitat diversity and amplified floods.
- Currently, governments write laws, issue directives, and fund voluntary actions to foster restoration of impacted streams to enhance aquatic habitat, possibly accompanied with flood protection reinforcement (e.g., the U.S. National Environmental Policy Act, the Canadian Environmental Protection Act or the European Water Framework Directive).
- Wohl *et al.* (2015) summarized the state of stream restoration in a general review.
- However, the legitimate question "**How do we approach river restoration?**" is not yet answered and society is spending a lot of money to build projects with sometimes low sustainability.
- We developed a canonic approach to standardize the engineering of sustainable stream restoration.

Requirements

- Quantitative and detailed records of the terrain and hydrodynamic exposure.
- River sections in which restoration is foreseen must be scanned and represented in digital elevation models.
- 2D modeling provides spatially discrete information on hydrodynamic forces as a function of flow depth, velocity, and energy slope.

Restoration feature layers

Layer 1: Terraforming creates new habitat through



Layer 2: Bioengineering stabilizes the terrain & enhances habitat

Layer 3: Maintenance features use gravel augmentation to sustain in-channel morphologies.

Lifespan mapping

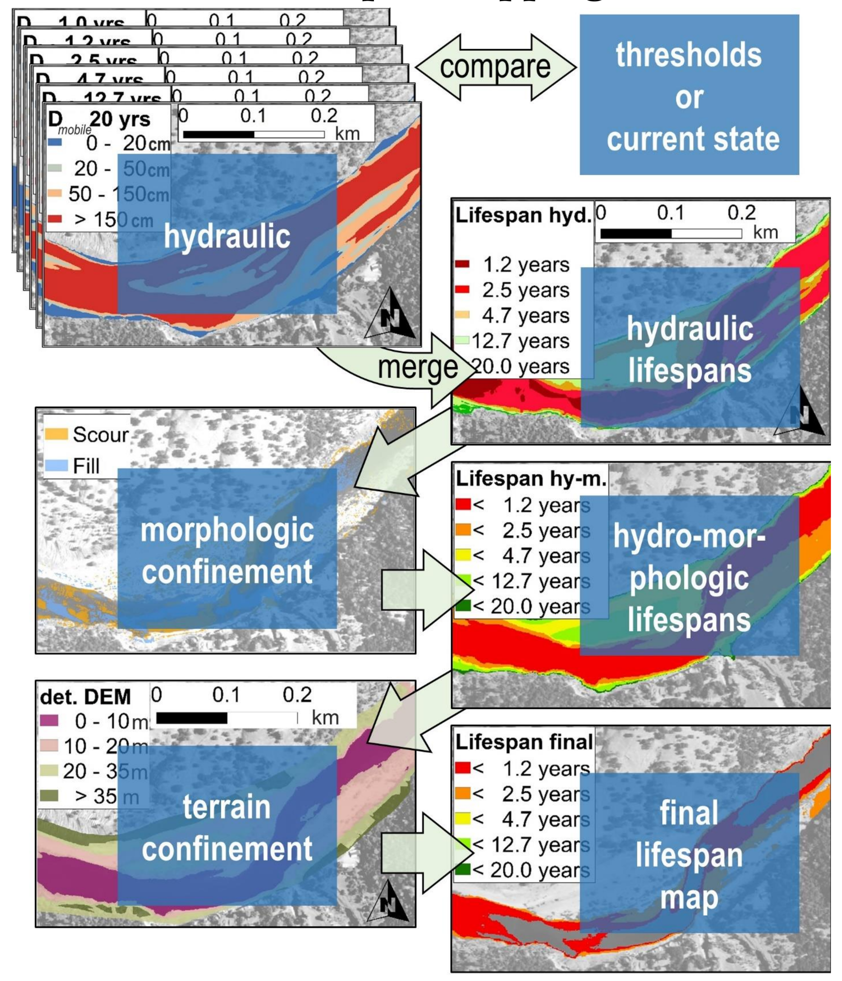


Figure 1: Lifespan mapping (Schwindt et al. 2019).

Habitat suitability vs. lifespans

- Lifespan maps of restoration features are based on 2D hydrodynamic modelling of flood discharges and terrain change maps (Schwindt *et al.* 2019).
- The hydraulic habitat suitability mapped as a function of preferred flow depths and velocities (2D modelling results) of target fish species indicates the habitat quality (Bovee 1986).
- The superposition of lifespan and habitat suitability maps points out where and what features are pertinent for habitat enhancement.

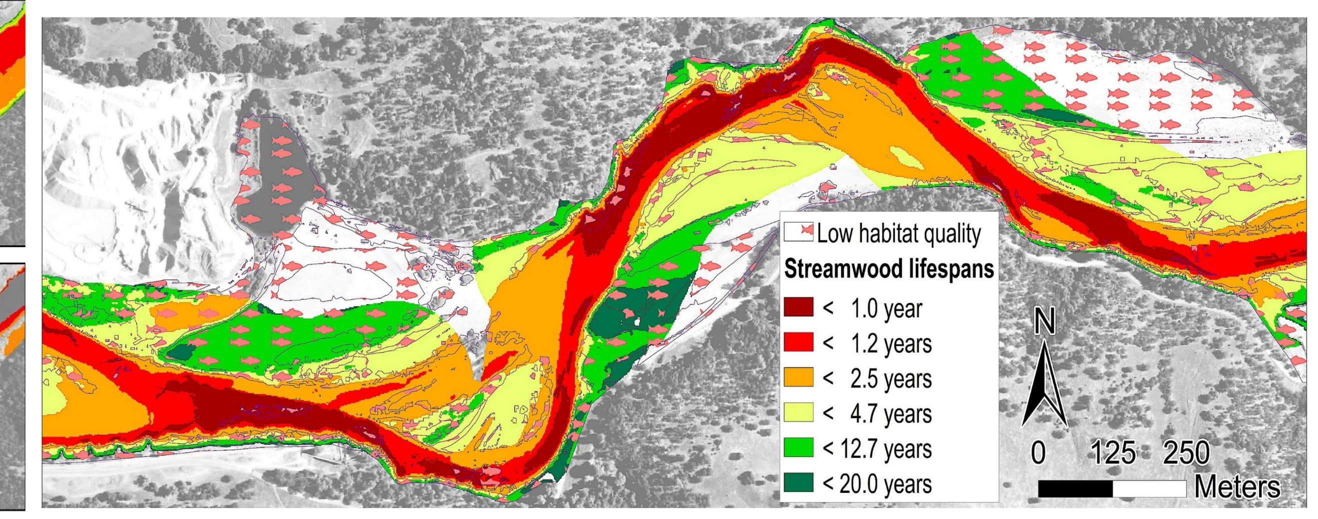
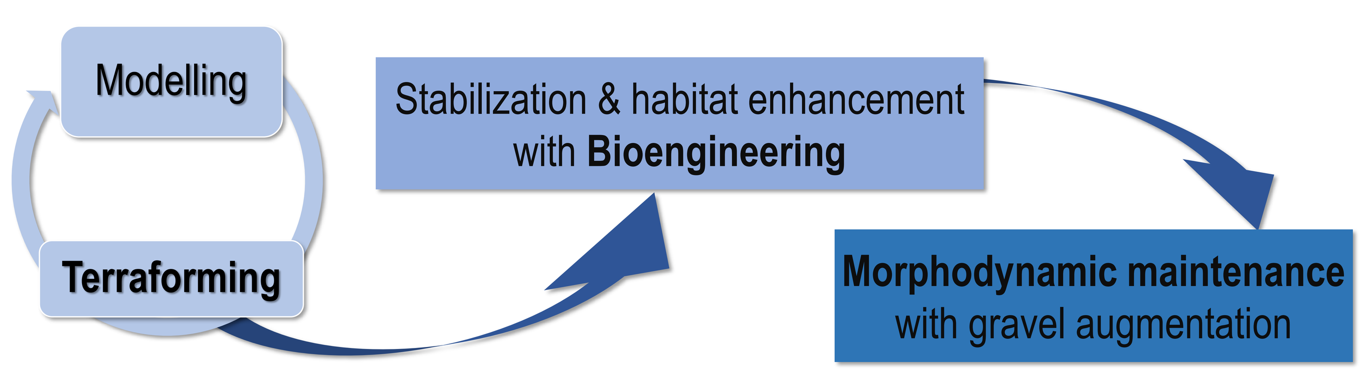


Figure 2: Feature lifespans and habitat quality indicate the pertinence of features.

Methods

The layer-wise approach

Our approach applies lifespan maps to layer-wise grouped features in an iterative assessment.



1) Terraforming iteration:
   a. Identify of best lifespans of terraforming features and application to the terrain with computer-aided drawing.
   b. Re-run the 2D hydrodynamic model for verification of habitat benefits and flood resistance.
   c. Adapt terraforming as a function of 2D hydrodynamic modelling. Iterate terraforming applies until the project restoration goals are achieved.
2) Bioengineering:
   a. Add indigenous plantings based on best lifespan maps showing most relevant species.
   b. Where planting lifespans are low (< 5 years), use (anchored) streamwood to support plantings.
   c. Where streamwood stability is low, use angular boulders to support living bioengineering features.
   d. Where new steep slopes are created, use laminar bioengineering features for stabilization.
3) Maintenance: Existing or newly created in-stream channel morphologies that are beneficial for indigenous aquatic species, such as riffle-pool sequences are maintained with gravel augmentation techniques.

Sample case

Habitat enhancement at the Yuba River, California

A 37.5-km segment of the Yuba River has been identified for habitat enhancement for the anadromous spring-run Chinook salmon, which is listed as threatened species under the federal Endangered Species Act. This wandering cobble-gravel bed river is characterized by mean grain sizes of approximately 0.04 m to 0.3 m, an average wetted baseflow width of 59.4 m and an average channel slope of approximately 0.17%. Several morphologically important discharges have been the focus of research and management on the Yuba River. The research products include hydrodynamic parameter and topographic change maps and provide a solid planning base for stream restoration. Schwindt *et al.* (2019) parametrize applicable restoration features and identify threshold values determining the features stability (Table 1).

Table 1: Threshold values of features applied at the Yuba River.

Parameter	(unit)	Berm set-back (Widen)	Calm water zones	Grading	Plants	Angular boulders	Side cavities	Side channels	Stream-wood	Other bioeng.
Depth to water	(m)	5 - 8	na	2 - 4	Var.	na	na	na	na	0 - 3
Shear stress	(--)	na	0.047	0.047	Var.	0.047	na	0.047	na	na
Flow depth	(m)	na	na	na	Var.	na	na	na	0.6·2	na
Flow velocity	(m/s)	na	na	na	Var.	na	na	na	na	na
Froude number	(--)	na	na	na	na	na	na	na	1	na
Morph. Unit	(string)	Yes	Yes	Yes	na	na	Yes	na	Yes	na
Fill	(m/year)	na	0.03	na	Var.	na	0.03	0.3	na	na
Scour	(m/year)	na	0.03	0.03	Var.	0.3	na	na	na	na

Figure 3: The candidate site for habitat enhancement at the Yuba River.

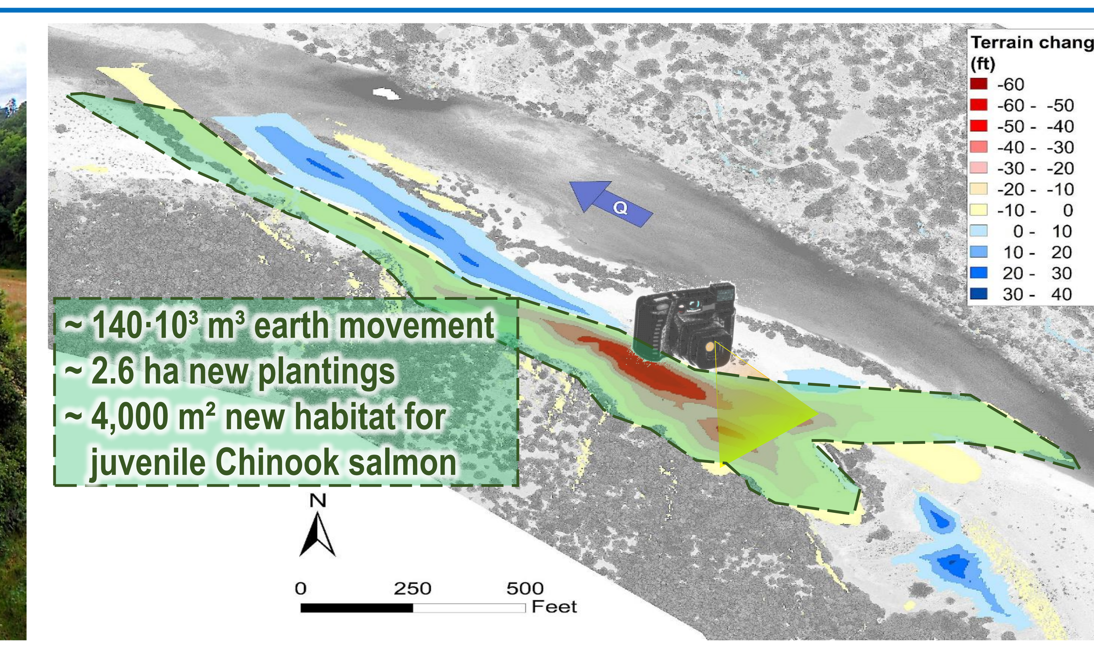


Figure 4: The terraforming plan is the result of iterative drawing and 2D modelling to meet side channel stability criteria.

The 2D modeling outputs of the terraformed site (Fig. 4) determines the canonic application of indigenous plant species (box elder, cottonwood, white alder and willows), streamwood, and angular boulders for stabilizing the modified terrain and further enhance newly created habitat (Fig. 5).

Maintenance features cannot be applied in the absence of a verified hydro-morphological model.

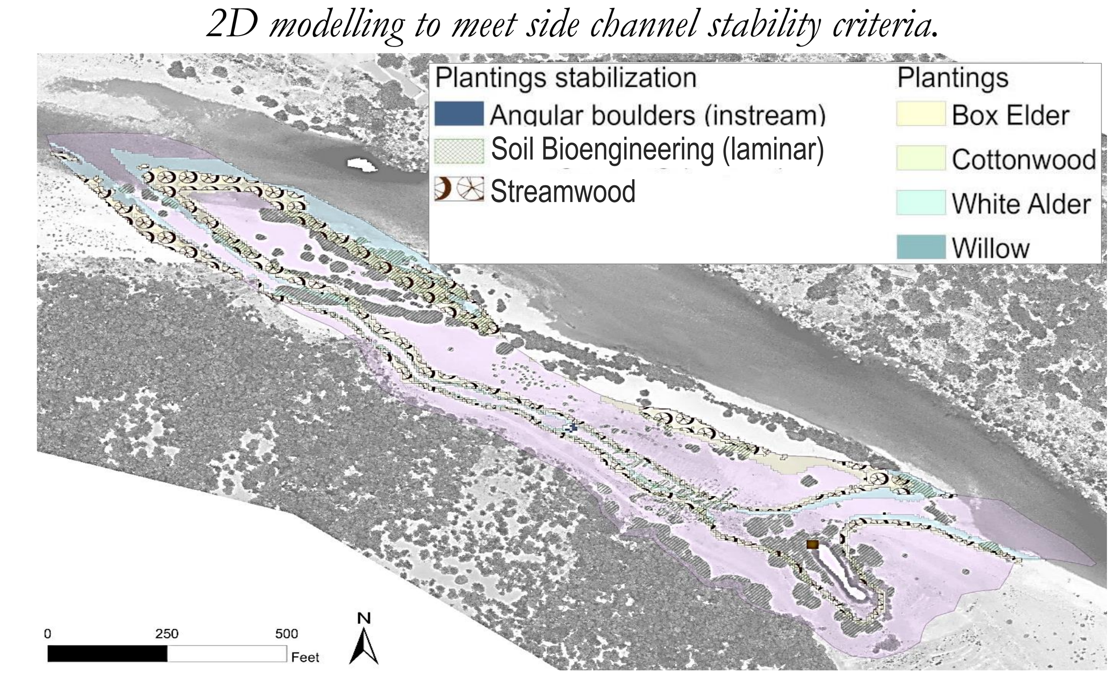


Figure 5: Stabilization with bioengineering.

Restoration plan

The habitat enhancement at the Yuba River aims at the connection of a gold-mining pit (Fig. 3) to the main channel, which involves grading of mining tails, side channel formation and the creation of a calm water zone. The necessary terraforming works were iteratively drawn to ensure the stability of the side channel and maximize the utility for juvenile Chinook salmon.

Conclusions & Outlook

- The developed approach enables an objective and systematic design of stream restoration projects.
- The restoration success is measurable in terms of gain in usable habitat area for target fish species.
- Maintenance features & improvements require sophisticated hydro-morphological models.

Outlook: We are developing software that automates the layer-wise approach – contact us for more information.

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