Automation of Ecological River Design: Opportunities and Challenges

Sebastian Schwindt[1] and Gregory Pasternack[2]

[1]University of California, Davis
[2]University of California at Davis

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Abstract

Sustainable concepts of ecologically functional rivers challenge engineers, researchers, and planners. Advanced numerical modeling techniques produce nowadays high-precision terrain maps and spatially explicit hydrodynamic data that aid river design. Because of their complexity, however, ecomorphological processes can only be reproduced to a limited extent in numerical models. Intelligent post-processing of hydrodynamic numerical model results still enables ecological river engineering measures to be designed sustainably. We have embedded state-of-the-art concepts in novel algorithms to effectively plan self-maintaining habitat-enhancing design features, such as vegetation plantings or the artificial introduction of streamwood, with high physical stability. The algorithms apply a previously developed lifespan mapping technique and habitat suitability analysis to terraforming and bioengineering river design features. The results not only include analytical synopses, but also provide actively created, automatically generated project plans, which are optimized as a function of an efficiency metric that describes "costs per m^2 net gain in seasonal habitat area for target species". To make the benefits of these novel algorithms available to a wide audience, we have implemented the codes in an open-source program called River Architect. In this contribution, we present the novel design concepts and algorithms as well as a case study of their application to a river restoration project on the Yuba River in California (USA). With River Architect, we ultimately created an objective, parameter-based, and automated framework for the design of vegetative river engineering features. In addition, we are able to define a framework for stable and ecologically viable terraforming features, but part of the planning of earthworks is still left to expert assessment. Thus, improving the algorithms to plan terraforming of permanent, self-sustaining, and eco-morphodynamic riverbed structures based on site-specific parameters is one of the future challenges.

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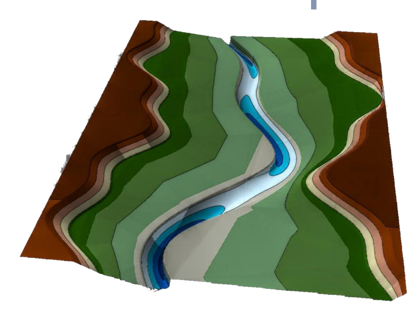
Sebastian Schwindt and Gregory B. Pasternack

Department of Land, Air and Water Resources | Watershed Hydrology, Geomorphology and Ecohydraulics | University of California at Davis | One Shields Avenue, Davis, CA 95616, USA | sschwindt@ucdavis.edu – https://sebastian-schwindt.org | gpast@ucdavis.edu – http://pasternack.ucdavis.edu

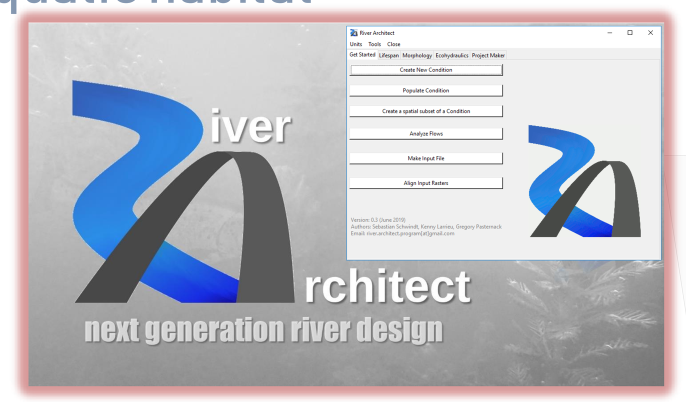
INTRODUCTION & METHODOLOGY

The design of River restoration and habitat enhancement involve geomorphologists, biologists and engineers. Working individually, every expert creates conceptual river landscapes, aquatic habitat optimized for target species or structural longevity of hydraulic bioengineering features. In a team consisting of geomorphologists, biologists and engineers, we have developed a parameter-based river habitat enhancement concept together with political actors and private parties. The concept parameterizes input data to perform the following design steps (Schwindt & Pasternack (2018) :

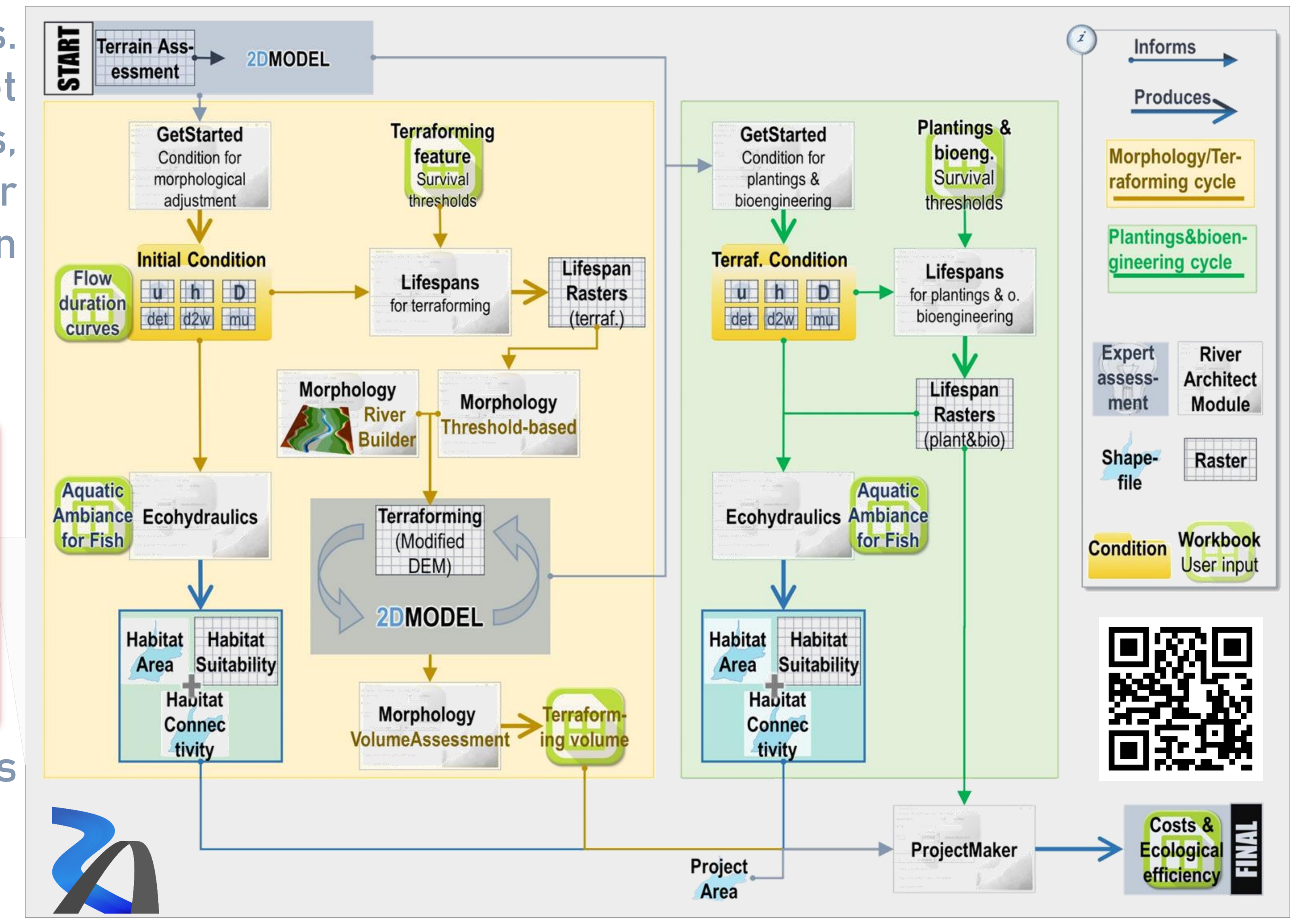
1) Assess lifespans (Schwindt et al. 2019) of nature-based engineering[G] features
2) Design & terraform to optimize nature-based engineering[G] survivorship and aquatic habitat



River Builder
http://RiverBuilder.ucdavis.edu



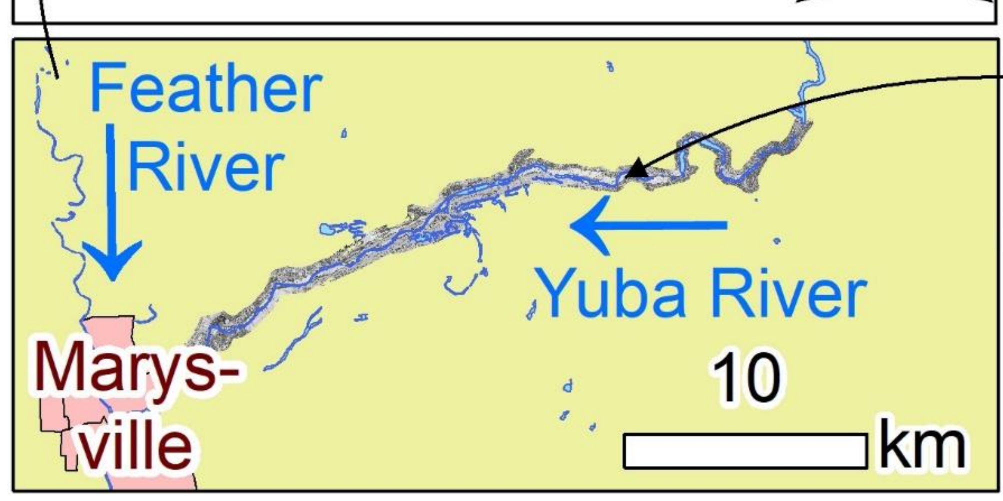
3) Calculate gain in seasonal habitat area SHArea[G] based on Habitat Suitability Curves[G] of target fish species and lifespans
4) Iterate over steps 1) to 3) to optimize lifespans and ecological utility
5) Estimate construction cost and project efficiency "Cost per are unit gained in SHArea[G]

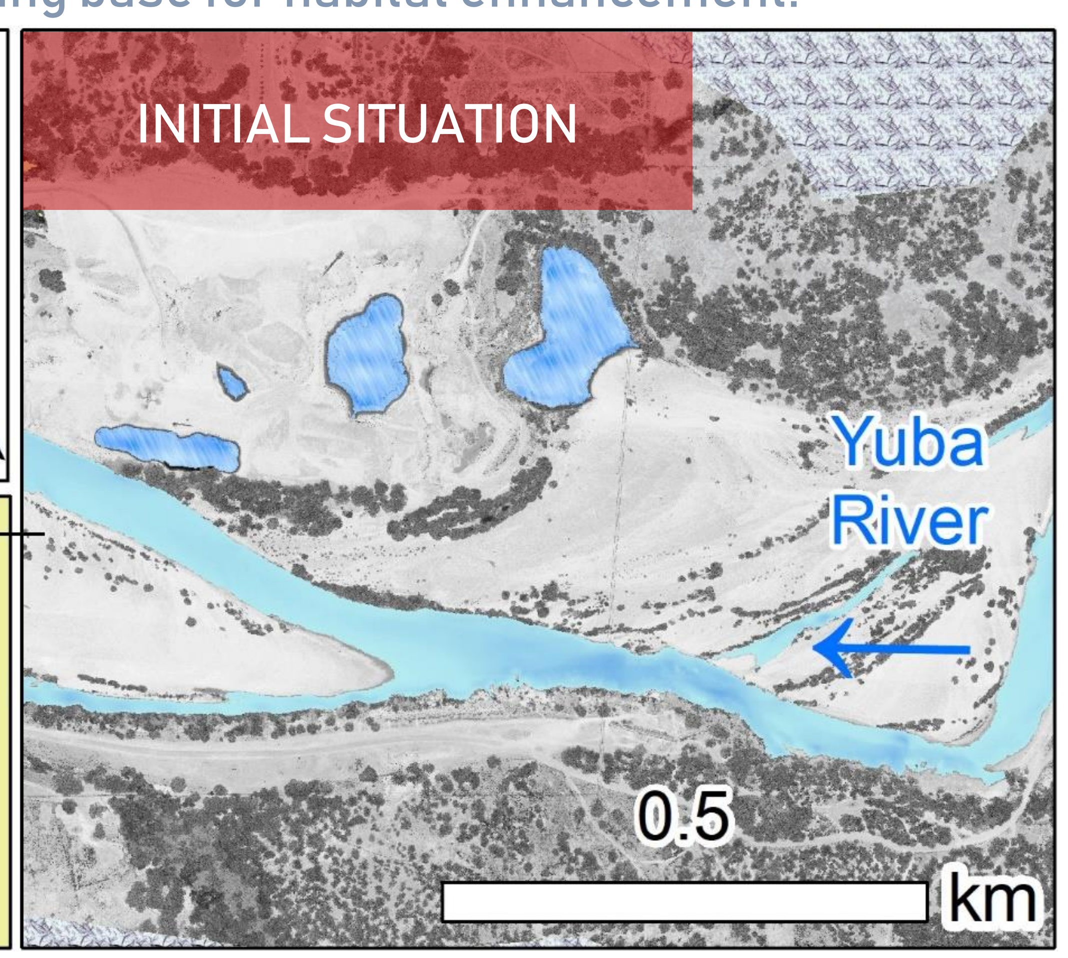


The parametrization of input variables enabled us to develop a Python3-based software called River Architect that automates our ecological and sustainable river design concept (Schwindt & Pasternack 2018). The software comes along with detailed documentation (Wiki) and can be downloaded using *git* from https://riverarchitect.github.io . River Architect applies the above flow chart (adapted from Schwindt et al. 2020).

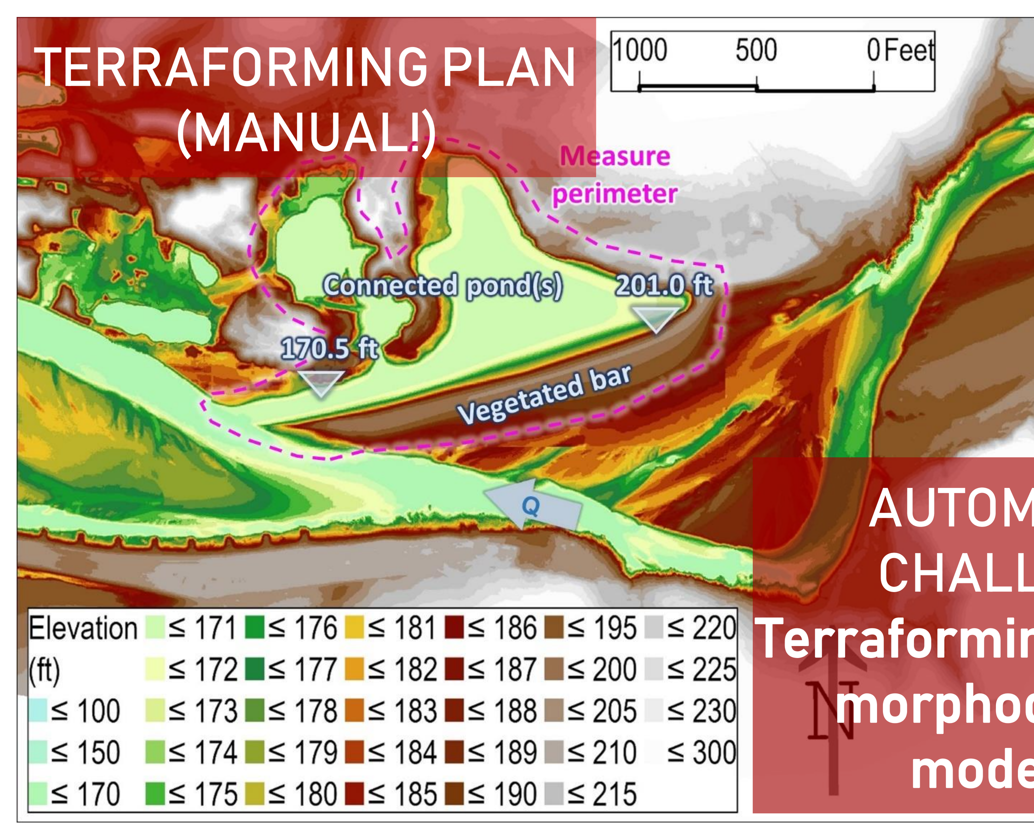
STUDY SITE

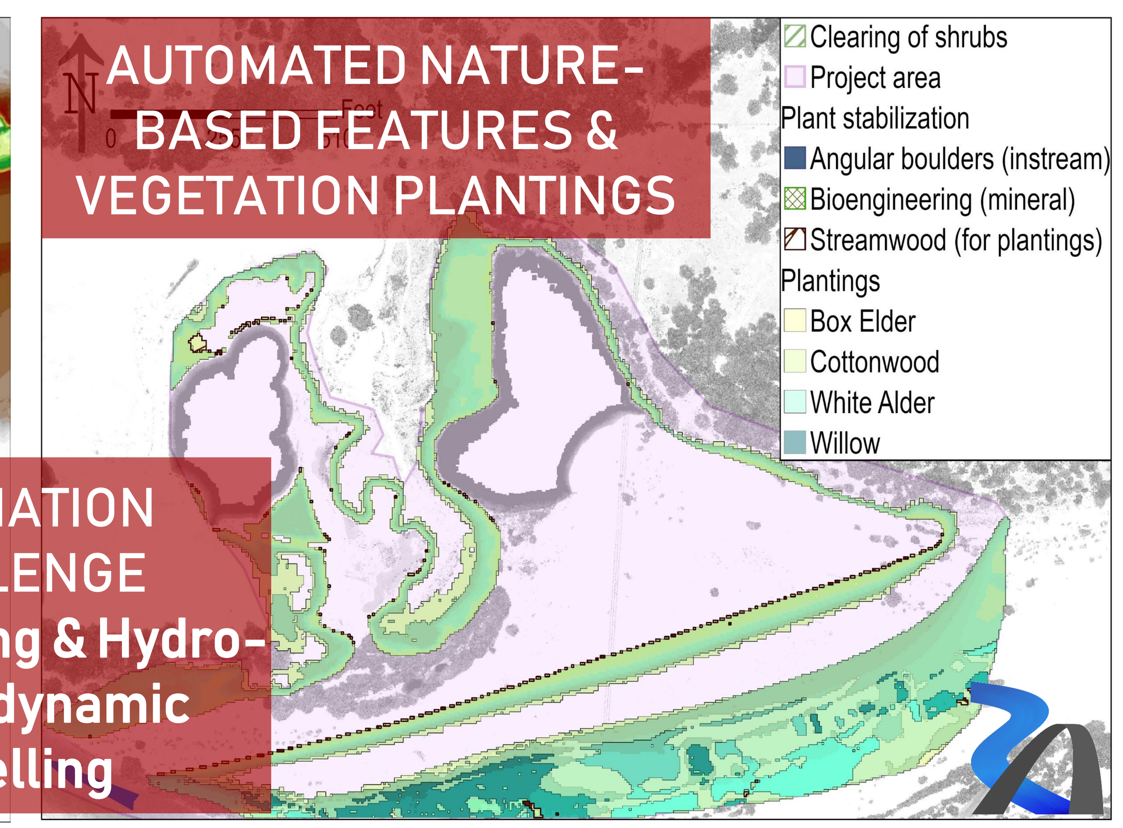
A 37.5-km stretch of the Yuba River has been identified for habitat enhancement for anadromous Chinook salmon (rearing from February to June), which is listed as threatened species under the federal Endangered Species Act. The dynamic cobble-gravel bed river is characterized by mean grain sizes of approximately 0.04m to 0.3m, an average wetted baseflow (25m³/s) width of 59.4 m and an average channel slope of 0.17%. The Yuba River has been in the focus of research on sediment and habitat dynamics since 1999. The research products include hydrodynamic parameter and topographic change maps, which provide a solid planning base for habitat enhancement.





RESULTS: SUSTAINABLE HABITAT WITH HALF-AUTOMATED DESIGN





Construction costs

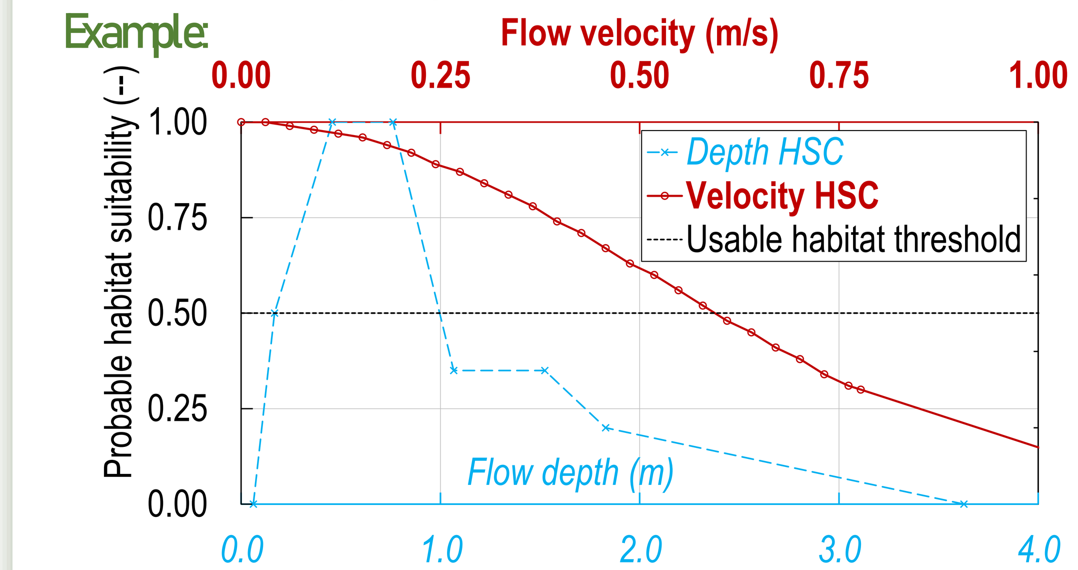
Position	Quantity	Unit	Costs (US $)
Terraforming (excavation dominates)	185,144	m³	$5,569,486.56
Vegetation Plantings	1,216,515	m²	$1,351,530.52
Stabilization of Vegetation Plantings	div.	div.	$377,283.67
Bioengineering (other)	3,642	m²	$686,070.00
Infrastructure improvements	--	m'	--
Support and Maintenance Features	--	--	--
Civil engineering	20.0	%	$1,597,080.02
Fees and Licensing	51.5	%	$4,112,481.04
Estimated Total Costs			**$12,518,689.66**
Net Gain in Seasonal Habitat Area (SHArea)	435,219	m²	$12,518,689.66
Cost per m² SHArea	**1.0**	m² gain in SHArea	**$28.76**

Discharge (m³/s)	Relative seasonal exceedance (% Feb-June)	Usable Area Before (m²)	Usable Area After (m²)	Time-weighted Area Before (%/100·m²)	Time-weighted Area After (%/100·m²)
2284.8	0.02	114,343	77,854	24	16
1713.6	0.05	124,226	110,023	31	28
965.7	0.34	168,460	123,767	495	364
325.5	2.93	7,088	84,509	184	2,190
169.4	12.15	3,895	155,936	359	14,368
141.6	17.54	3,847	519,169	208	28,027
113.3	35.47	4,562	534,920	818	95,863
97.8	40.44	5,436	534,872	270	26,607
85.0	46.02	5,815	531,349	325	29,663
63.9	56.54	7,019	516,307	738	54,305
63.6	56.66	7,046	516,100	8	606
56.6	60.19	7,852	511,132	277	18,038
42.5	71.94	11,182	500,961	1,314	58,875
36.8	76.59	14,767	483,758	687	22,520
28.4	84.53	19,178	453,240	1,523	35,989
26.3	86.83	20,437	446,834	470	10,273
24.9	87.59	21,132	440,585	159	3,323
23.1	88.91	22,041	432,789	291	5,708
20.7	97.31	23,073	421,387	1,938	35,401
17.6	98.14	24,263	403,275	202	3,352
15.0	99.80	24,945	26,403	415	439
	SHArea ∑			10,736	445,955

GLOSSARY

Nature-based engineering = Part-discipline of civil engineering that makes use of locally available, living materials and minerals; substitute for rigid hydraulic engineering structures (Zeh, 2007). Examples:

Habitat Suitability Curve = Indicator function of preferred hydraulic criteria (flow depth & velocity) by target fish species and their life stages; 1=preference and 0=avoidance (Bovee 1986). Example:



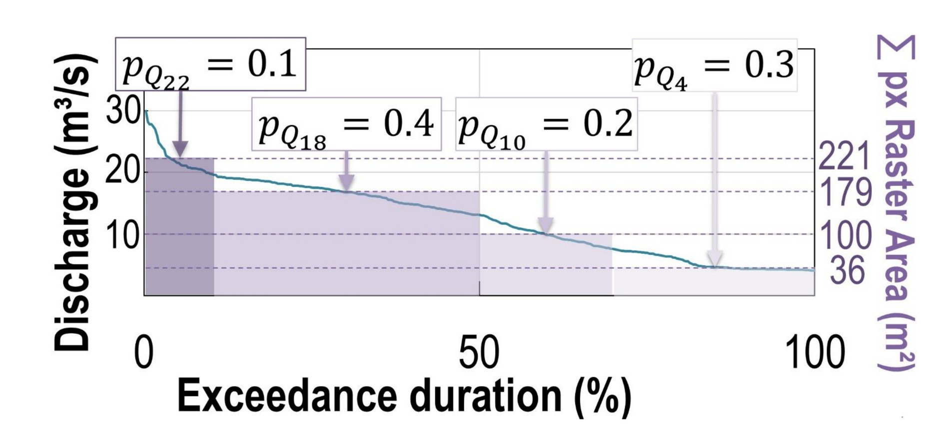
These curves define the Depth Habitat Suitability Index (DHSI) and Velocity Habitat Suitability Index (VHSI). The geometric mean of both constitutes the combined Habitat Suitability Index:

$cHSI = \sqrt{DHSI \cdot VHSI}$

SHArea (Seasonal Habitat Area) =

$\sum_{p_{Qi}}^{p_{Qn}} [\sum px(cHSI > \vartheta) \cdot A_{px}] \cdot p_{Qk}$

where $px(cHSI > \vartheta)$ denotes all raster pixels where cHSI is higher than a threshold value ϑ; A_{px} is the area (size) of pixels; p_{Qk} is the relative duration (presence) of a raster during a fish season, associated with a discharge Q_k.



SHArea = 0.1·221+0.4·179+0.2·100+0.3·36=124.5m²
(source: Schwindt et al. 2020)

More about River Architect: Poster EP41C-2335 by K. Larrieu, Thursday 08:0 0-12:20

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