# Appendix F. Geomorphic Classification of California Rivers

Samuel Sandoval Solis, Belize A. Lane, Gregory Pasternack, Colin Byrne, Herve Guillon

Classification of channel reach geomorphic settings serves as a method to organize heterogeneous geomorphic and hydraulic conditions across entire stream networks. This information can be used to prioritize key flow metrics expected to be most significant in different geomorphic settings, stratify ecological response relationships, or extrapolate resource intensive information collected at a single site to other locations with similar settings.

This document describes the development of geomorphic classifications for rivers in nine regions of the state that can be used in the CEFF process in several ways, including:

- In Step 6 for supporting the assessment of geomorphic conditions in terms of the spatial distribution of different channel types and associated geomorphic processes in the geographic region, and
- In Step 6 for the development of indirect ecological response relationships that are mediated through geomorphology and hydraulics. Specifically, the geomorphic classification facilitates the development of distributed hydraulic response relationships that can be linked with species preferences/tolerances to obtain ecological response relationships at LOIs across a stream network as detailed in Appendix G.

The result of the geomorphic classification is a list and descriptions of channel types that are likely to occur in the region as well as a geodatabase of the classified stream network at the 200-m segment scale. The descriptions of each channel type include details on the characteristic geomorphic attributes (e.g. bankfull width and depth, slope, etc.), topographic variability attributes (e.g.coefficient of variation of bankfull depth) and sediment composition (e.g. d50 and d84).

This appendix provides a high-level summary of the geomorphic classifications of rivers and streams in the state of California. **For more extensive descriptions of the input data, methods and results of the regional geomorphic classifications, the user should refer to the specific documents in Table 1.** The appendix briefly introduces the data collection, classification and prediction methods, key results, and where to obtain additional information. Regional classifications were developed for eight regions.

Table 1.- Key documentation of the geomorphic classification of California

| **Documentation** | **Information** |
|---|---|
| Geomorphic Classification Technical Reports to Water Board | Description of input data, methods, results, uncertainty analyses for Sacramento Basin (Byrne et al. 2019), Coastal Regions (Byrne et al. 2020), and South Fork Eel River (Guillon et al. 2019) watersheds |
| Byrne et al. (2020) | Peer-reviewed publication with detailed description of statistical methods used to develop regional classifications |
| Guillon et al. (2020) | Peer-reviewed publication with detailed description of machine learning algorithm used to predict channel types across the stream network |

**Introduction to geomorphic classification**

Reach-scale geomorphic settings (e.g., pool-riffle, step-pool) distinguished by physical attributes related to channel form and sediment transport and supply have been shown to influence ecosystem dynamics and biological diversity, highlighting channel reach classification as a critical step in river ecosystem management. Geomorphic attributes used in channel classification are often chosen to describe relevant and persistent reach-scale characteristics that influence biological response through distinct controls on hydraulic conditions and fluvial processes. To better understand how managed environmental flow prescriptions will impact native biota throughout the streams and rivers of California, knowledge of the types and distributions of physical habitat settings is critical.

Geomorphic classifications were developed for eight management regions: The management regions included the  South Fork Eel River, Klamath (K), North Coast (NC), North Central Coast (NCC), Sacramento (SAC), South Central Coast (SCC), South Coast (SC), San Joaquin Tulare (SJT), and Southeastern California (SECA). Here we provide a brief overview of methods and results from each of the geomorphic classifications, except SECA and SJT which were completed later. A geomorphic channel type is defined here as an archetypical stream form at the 10 – 20 channel width scale that has: (a) well-defined channel attributes (e.g. slope, bankfull width, etc.), (b) topographic variability attributes (e.g. coefficients of variation of width and depth), (c) sediment composition (e.g. D50, D84, etc.) and (d) landscape setting (e.g. valley confined, partly confined or unconfined) that can be verified in the field (Byrne et al. 2020).

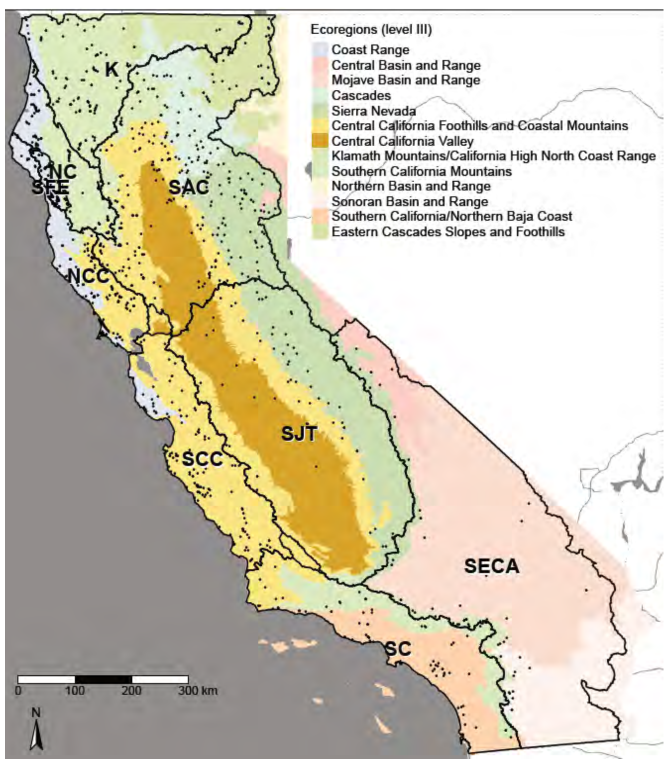



Figure 1 - Map of nine management regions and 1,100 field site locations across California.

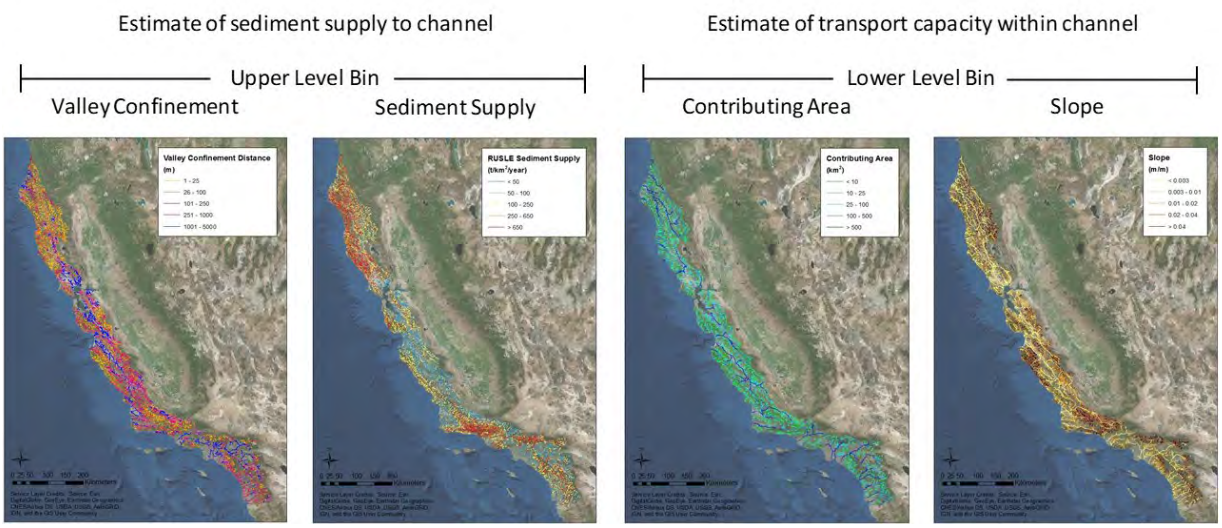
## Summary of methods

The methods are briefly outlined below, including field site selection and data collection, geomorphic classification and spatial prediction.

***Field site selection and data collection***

The geomorphic classifications in the coastal regions (i.e. excluding SECA and SJT) were informed by 886 field-surveyed reaches (Figure 1): Sacramento (290), Klamath (105), North Coast (104), Central Coast North (104) and South (119), South Coast (67), and South Fork of the Eel River (97).

- Site selection process:




- High-level overview of field surveying protocols:

Key attributes used in channel classification defined at *bankfull* stage:

- Contributing drainage area
- Mean water surface slope
- Mean thalweg depth
- Mean top width
- Width-to-depth ratio
- Coefficient of variation in depth
- Coefficient of variation in width
- D50
- D84
- Valley confinement distance

Two cross-sectional survey protocols were used in the South Fork Eel catchment:

- Equidistant cross-sections (73 sites)
- Equidistant cross-sections with pool troughs and riffle crests also measured (24 sites)

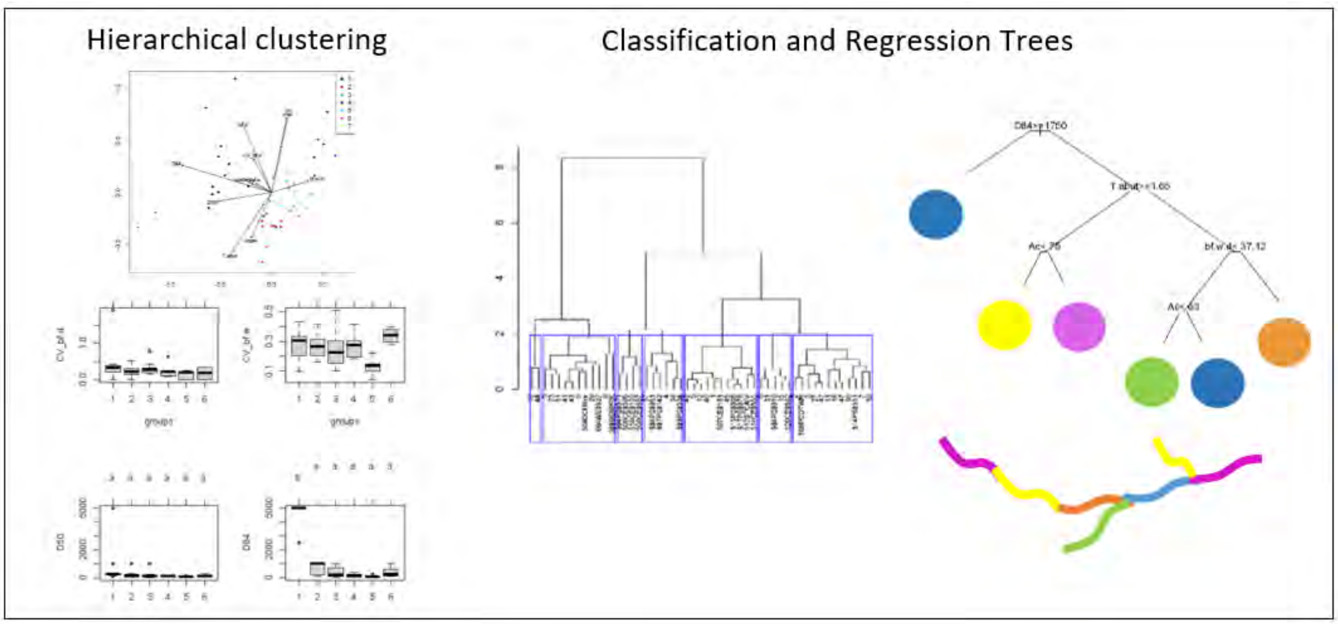
Classification was conducted primarily with the following two statistical methods:

- Hierarchical clustering based on multidimensional distances between sites
- Cross-validation of classified sites using classification trees

All the protocols are available for Year 1 surveys (protocol and datasheet) and Year 2 surveys (Protocol). The data collected as well as the protocols will be hosted in the Surface Water Ambient Monitoring Program (SWAMP) website.

***Overview of Classification Methods***

Surveyed streams were analyzed using multivariate statistical techniques to identify groups of reaches with similar geomorphic attributes. Four groups of variables were calculated from the data collected: channel attributes (e.g. slope, bankfull width, etc.), topographic variability attributes (e.g. coefficients of variation of width and depth), sediment composition (e.g. D50, D84, etc.) and landscape location (e.g. valley confined, partly confined or unconfined). These variables were used in the classification analysis to identify groups of reaches with similar stream forms. Classification was conducted primarily using two statistical methods: (1) hierarchical clustering based on multidimensional distances between sites and (2) cross-validation of classified sites using classification trees. Using both statistical methods allow to classify each field site into a channel type and cross-validate this classification by predicting the channel type group using the four groups of variables aforementioned.




***Overview of Spatial Prediction Methods***

Within each region, the classified channel types of all the field-surveyed sites in the region (described above) were used as the training set to spatially predict the channel type of each 200-m stream segment within the region. The classified field sites were incorporated as labels into a large-scale supervised machine-learning model that predicted channel types based on over 100 watershed characteristics including topography, geology, soils, climate and land use. Details of this method can be found in Guillon et al (2020).

The regional models generally performed well, the accuracy of the machine learning models was determined using the median value of the cross validation process. The datasets used in machine learning applications are often divided into a training set and a testing set; the training set is used to tune the hyper-parameters and the testing set to assess the accuracy. In the case of smaller datasets, resampling allows all data to be used both in training and in testing. The most common resampling is the n-fold cross-validation (Burman 1989) with n=10. In such 10-fold cross-validation, the data are randomly separated in 10 parts or folds. Successively, 1 fold is held out and the 9 other folds that are used to train the classifier(s). The performance of the classifiers is assessed against the hold-out fold. The reported accuracy is then often the median over 10 cross-validation accuracies and yields an estimate of the performance of the classifier against unseen data. In our case, 20 repeats of 10-fold cross-validation were used to address the bias that might be introduced by the initial random selection of the folds. The median cross-validation accuracies were estimated over the accuracy from 200 different folds.

| **Region** | **Cross Validation accuracy** |
| --- | --- |
| South Fork Eel River | 77% |
| Sacramento River (SAC) | 61% |
| Klamath (K) | 99% |
| North Coast (NC) | 94% |
| North Central Coast (NCC) | 97% |
| South Central Coast (SCC) | 98% |
| South Coast (SC) | 93% |

In addition, the spatial significance of the model predictions from the best models was assessed using expert-knowledge and aerial imagery, with a focus on the general spatial organization of channel types across the different regions as well as their geomorphic relevance.

### *Overview of Results*

The resulting geomorphic classifications and spatial predictions are shown below for the Sacramento (Figure 2), Klamath (Figure 3 and 4), North Coast (Figure 5 and 6), Central Coast North (Figure 7 and 8) and South (Figure 9 and 10), South Coast (Figure 11 and 12), and South Fork Eel River Basins (Figure 13). More detailed information about the classifications and channel types in each region can be found in the Byrne et al. (2019) and Guillon et al. (2019 and 2020).

**Sacramento River Basin**

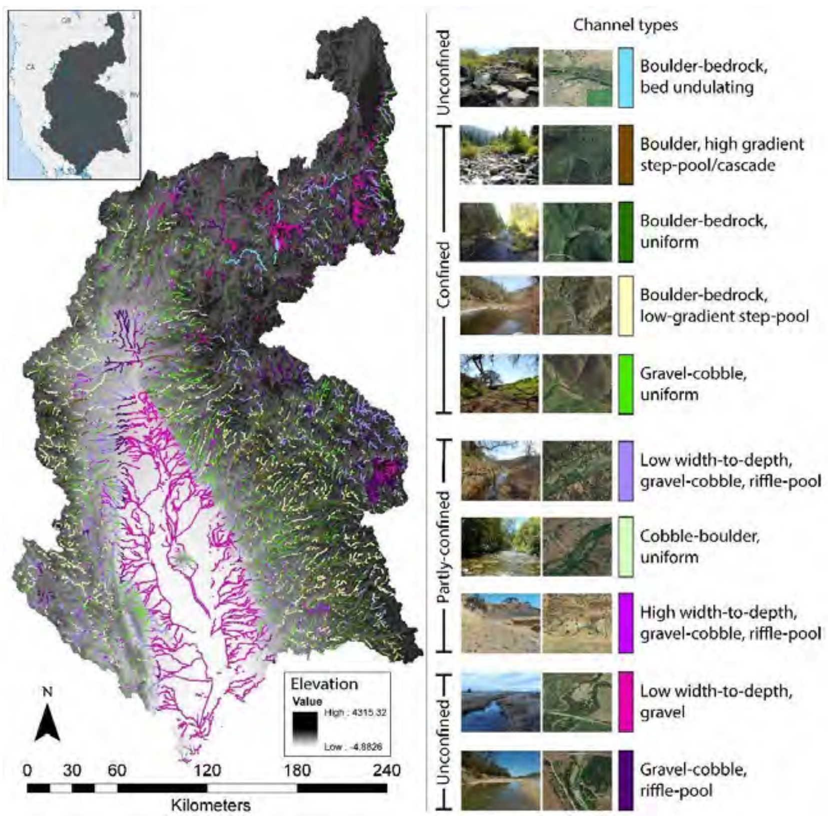



Figure 2.- Geomorphic classification and spatial distribution of channel types in the Sacramento River Basin

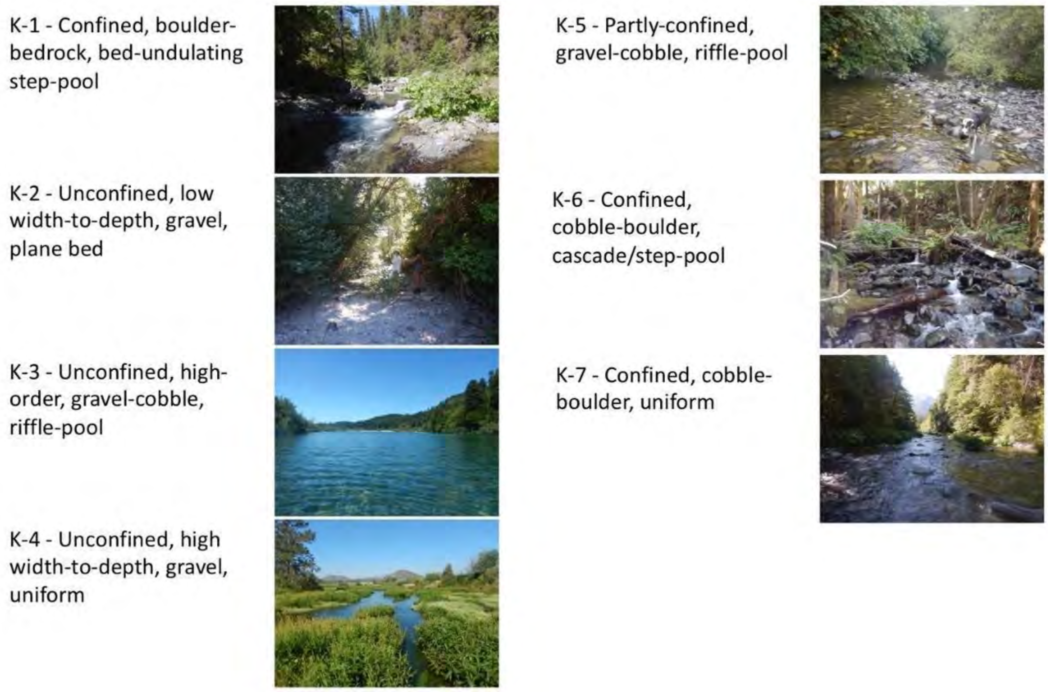



Figure 3. The seven channel types within the Klamath region

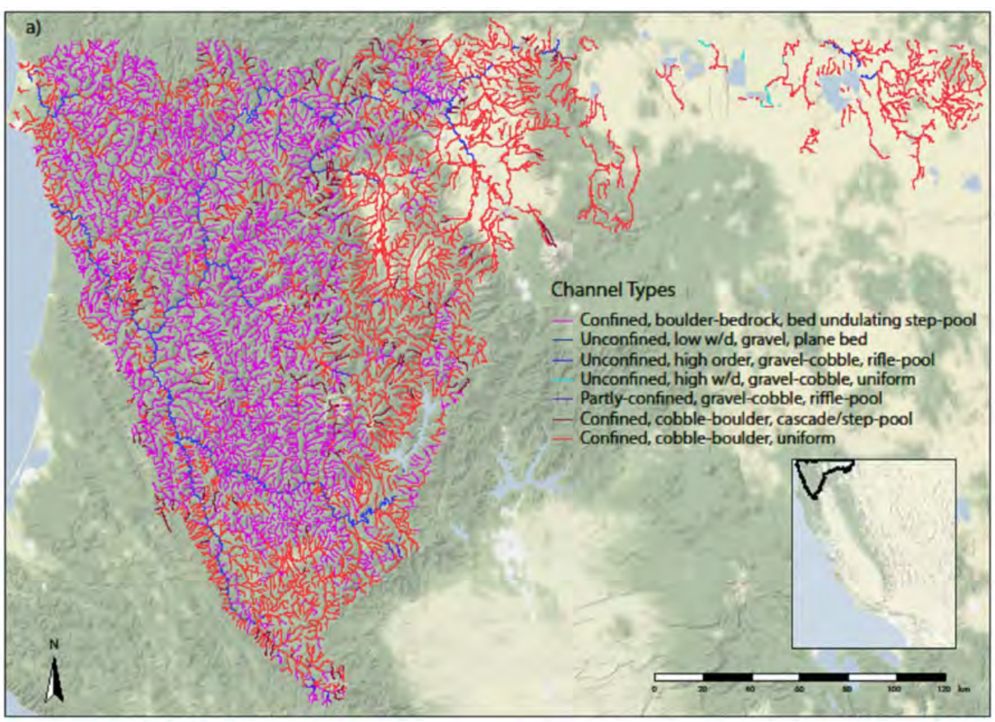



Figure 4. Spatial prediction of the seven channel types within the Klamath region


Figure 5. The eight channel types within the North Coast region

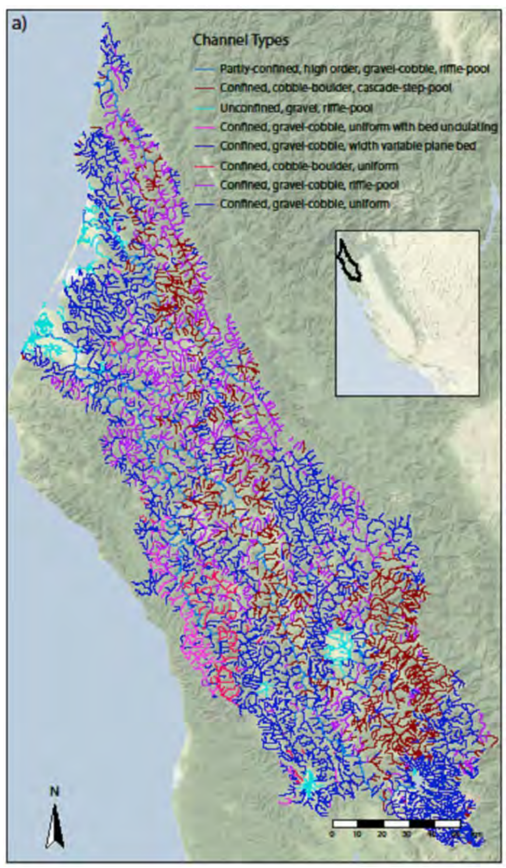



Figure 6. Spatial prediction of the eight channel types within the North Coast region


Figure 7. The six channel types within the North Central Coast region

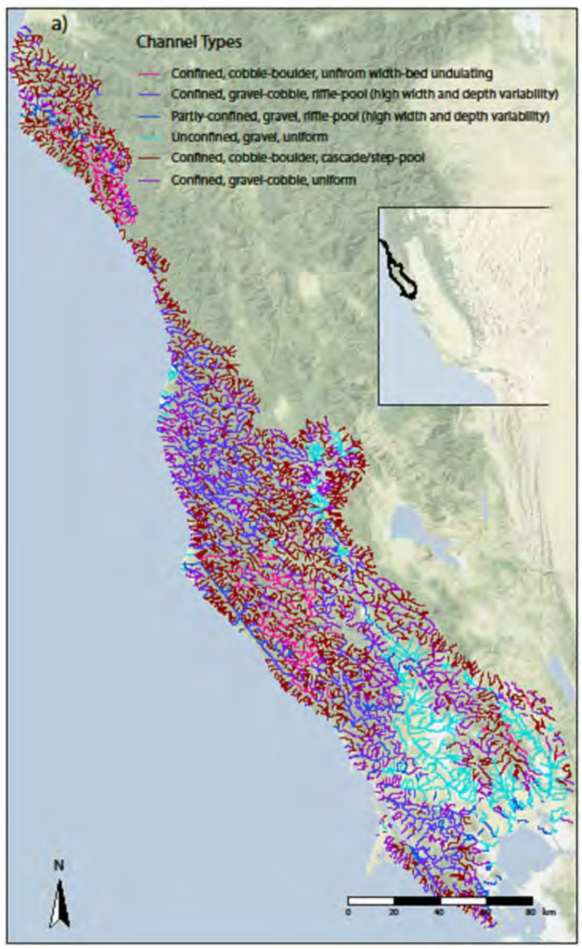



Figure 8. Spatial prediction of the six channel types within the North Central Coast region


Figure 9. The eight channel types within the South Central Coast region

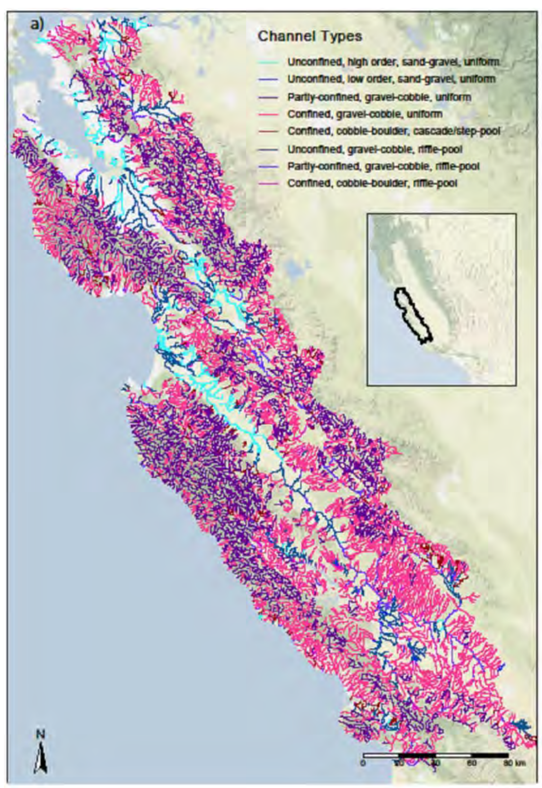



Figure 10. Spatial prediction of the eight channel types within the South Central Coast region


Figure 11. The five channel types within the South Coast region

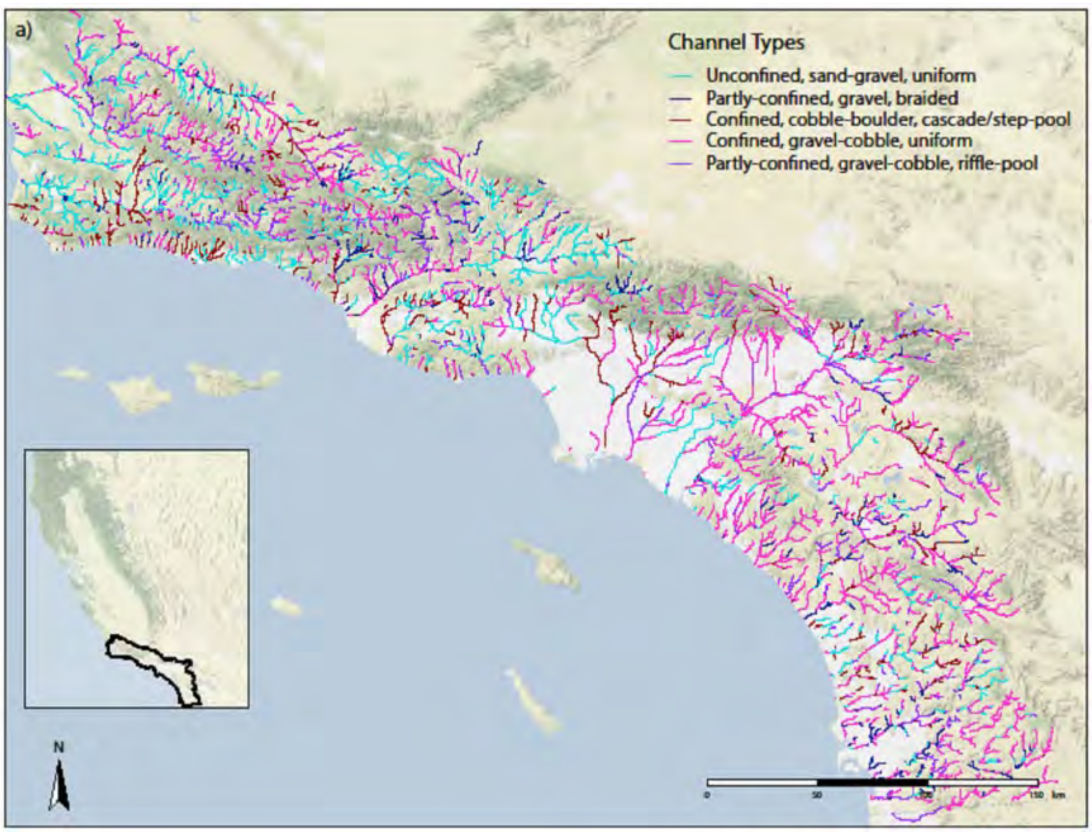



Figure 12. Spatial prediction of the five channel types within the South Coast region

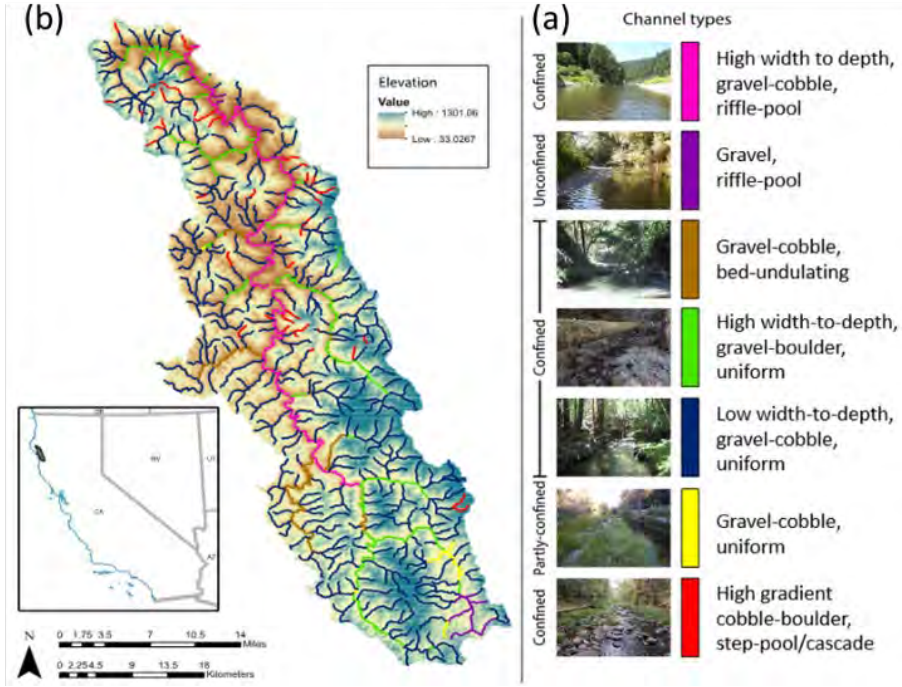



Figure 13. Geomorphic Classification and Spatial prediction of the six channel types within the South Fork of the Eel river region

## References


Anim, D.O. Fletcher, T.D., Pasternack, G.B., Vietz, G.J., Duncan, H.P., and Burns, M.J. (2019). Can catchment-scale urban stormwater management measures benefit the stream hydraulic environment? Journal of Environmental Management, https://doi.org/10.1016/j.jenvman.2018.12.023

Brown, R., Pasternack, G., and Wallender, W., 2014. Synthetic river valleys: creating pre-scribed topography for form–process inquiry and river rehabilitation design. Geomorphology 214, 40–55. https://doi.org/10.1016/j.geomorph.2014.02.025.

Brown, R.A., Pasternack, G.B., and Lin, T., 2016. The topographic design of river channels for form-process linkages. Environ. Manag. 57 (4), 929–942. https://doi.org/10.1007/s00267-016-0663-9.

Burman, Prabir. 1989. "A Comparative Study of Ordinary Cross-Validation, V-Fold Cross-Validation and the Repeated Learning-Testing Methods<." *Biometrika* 76 (3). JSTOR: 503. doi:10.2307/2336116.

Byrne, C.F., Pasternack, G.B., Guillon, H., Lane, B.A., and Sandoval-Solis, S. (2020). Reach-scale bankfull channel types can exist independently of catchment hydrology. J. Earth Surface Processes and Landforms. DOI: 10.1002/esp.4874

Byrne, C.F., Guillon, H., Lane, B.A., Pasternack G.B. and Sandoval-Solis, S. (2019). Sacramento River Basin Geomorphic Classification. Final Report. Submitted to the California State Water Resources Control Board. Davis, California. February 2019.

Byrne, C.F., Guillon, H., Lane, B.A., Pasternack G.B. and Sandoval-Solis, S. (2020). Coastal California Regional Geomorphic Classification. Final Report. Submitted to the California State Water Resources Control Board. Davis, California. February 2019.

Guillon, H., Byrne, C.F., Lane, B.A., Pasternack G.B. and Sandoval-Solis, S. (2019). South Fork of the Eel River Basin Geomorphic Classification. Final Report. Submitted to the California State Water Resources Control Board. Davis, California. February 2019. [Report]

Guillon, H., Byrne, C.F., Lane, B.A., Sandoval-Solis, S., and Pasternack G.B. (2020). Machine Learning Predicts Reach-Scale Channel Types from Coarse-Scale Geospatial Data in a Large River Basin. J. of Water Resources Research. https://doi.org/10.1029/2019WR026691 [Article]

Lane, B.A., Pasternack, G.B., Dahlke, H.E., and Sandoval-Solis, S. (2017). The role of topographic variability in river channel classification. J. Progress in Physical Geography: Earth and Environment. https://doi.org/10.1177/0309133317718133

Lane, B.A., Pasternack, G.B., and Sandoval-Solis, S. (2018). Integrated analysis of flow, form, and function for river management and design testing. Journal of Ecohydrology. DOI:10.1002/eco.1969