CONSERVATION SCIENCE PARTNERS

METHODOLOGICAL OVERVIEW

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For the project entitled:

National Functional Floodplains Assessment of the United States

Points of contact:
Lise Comte, Lead Scientist, lise@csp-inc.org
Julian Olden, Senior Associate Scientist, julian@csp-inc.org

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Table of contents

Versions

Version 1.0 – Released July 2025
Original release of the *National Functional Floodplains Assessment of the United States.*

1. Overview

Conservation Science Partners, in partnership with American Rivers, has developed the *National Functional Floodplains Assessment (NFFA) of the United States*, a data-driven nationwide inventory of present-day floodplain protection status and alteration. The NFFA helps conservation practitioners, policymakers, scientists, and the public understand the current state of floodplain protection and alteration and identify opportunities to expand protection and scale up restoration efforts in the coming years. This assessment leverages a large array of datasets capturing the different mechanisms conferring protection to floodplains, including river conservation (e.g., Wild and Scenic River corridor designations), riparian and floodplain conservation (e.g., Riparian National Conservation Areas, Emergency Watershed Protection – Floodplain Easements, Northwest Forest Plan Riparian Reserves), policies focusing on endangered species (Endangered Species Act Critical Habitat), and terrestrial protected areas (e.g., National Wilderness Preservation System, National Parks, Areas of Critical Environmental Concern). The extent of protection was then summarized at the watershed and state scales, considering both overall protection and protection after excluding multiple use lands. In parallel, a Floodplain Alteration Index (FAI) was developed to assess the degree of alteration with respect to the lateral connectivity, flow regime, and habitat integrity of local floodplains. Finally, a set of additional variables capturing the values and threats to floodplains was summarized to provide contextual information in support of prioritizing protection and restoration.

Details regarding the selection of protection mechanisms, a summary of the extent of protection, computation of the FAI, and additional contextual variables are provided in the following sections. The Final Report (CSP 2024) provides further details.

2. Disclaimer

We offer several cautionary notes regarding the NFFA, as reported here. The completeness of the protected area databases underlying this assessment varies through space and stewardship, compiling "best available" data provided by managing agencies and organizations. We collated additional datasets to fill some key knowledge gaps in floodplain protection, including an inventory of federal and state wild and scenic rivers and associated land corridors, regional (through the Aquatic Conservation Strategy of the Northwest Forest Plan for federal forests) and state-level (through buffer ordinances and forest practices administrative rules) riparian protection. However, the estimates of floodplain protection reported here will change as new protected areas are added to the databases underlying the analyses and data quality continues to improve. Complementary datasets related to instream flow rules or related to groundwater protection could be incorporated in future updates as they become available.

We also note that the underlying spatial framework used to depict floodplains across the U.S. is likely to influence the total number of floodplain acres considered protected or not. Nonetheless, given current spatial gaps in the Federal Emergency Management Agency's (FEMA) Flood Hazard Areas layer, using a modelled floodplain layer has the advantage of facilitating downstream analyses (by estimating protection and alteration using the same underlying layer) and avoiding biases towards certain mechanisms or datasets because of the nature of the underlying spatial layers used. The names of the watersheds follow the names provided with the data; however, they may contain inaccuracies and/or may not reflect recent updates. Finally, we acknowledge that despite its sophistication, there are additional opportunities for further improvement of the FAI. Future versions of the FAI could integrate other aspects of floodplain alteration, such as changes in seasonal inundation patterns and sediment trapping.

3. Floodplain extent

A floodplain can be defined as a low-lying ground area adjacent to a stream or river, subject to periodic flooding and characterized by deposition sediments (Tockner & Stanford, 2002). Floodplains are thus dynamic systems, making them challenging to identify and map over large spatial extents. Here, the delineation of floodplains across the U.S. relies on the open source GFPLAIN algorithm, which builds on hydrogeomorphic analysis to identify floodplains based on Digital Elevation Models (DEM) and channel flow depth-contributing area scaling laws (Nardi et al., 2013, 2019). The GFPLAIN algorithm has the advantage of not relying on the availability of hydrologic data and is considered computationally efficient, while presenting relatively low uncertainties as compared to other approaches (Lindersson et al., 2021). The GFPLAIN algorithm preprocesses the data for analysis (i.e., DEM pit filling, determination of flow direction and flow accumulation), and then estimates the 100-year floodplains based on a scaling regression that relates channel flow height to upstream basin area (Leopold & Maddock, 1953).

For the contiguous U.S., we used the floodplain delineation previously performed by Knox et al. (2022a) using the GFPLAIN algorithm based on the 30-m resolution USGS National Elevation Dataset and regional flow depth-contributing area scaling regressions calibrated using the FEMA National Flood Hazard Layers at the HUC2 scale. We created one single floodplain polygon by dissolving both the agreement and anthropogenically modified floodplain polygons provided in the layer, which correspond to floodplains that have been estimated to be altered or not by the construction of artificial levees, respectively (Knox et al. 2022a). Next, we divided the national floodplain layer into local floodplains using the National Hydrography Dataset Plus v2.1 catchment boundaries (NHDPlus v2.1; McKay et al., 2012; USGS, 2023a), allowing each local floodplain to be associated with a unique NHD stream segment.

Next, we ran the GFPLAIN algorithm for Alaska and Hawaii separately, using the USGS 3D Elevation Program DEM resampled at a 30-m resolution with bilinear interpolation (USGS, 2023b). Due to the paucity of FEMA National Flood Hazard Layers, we used the scaling parameters that presented the highest measures of fit during floodplain calibration across HUC2s [a = 0.0035 and b=0.34] as reported by Knox et al. (2022a). Following previous work, we selected 50 km^2 for the contributing area threshold for Alaska, but selected 20 km^2 for Hawaii to account for the fact that drainage basins are commonly small (USGS, 2023c). Similar to the contiguous states, the floodplain layer for Hawaii was further divided into local floodplains using the NHDPlus v2.1 catchment boundaries, allowing each local floodplain to be associated with a unique stream segment. Due to the lack of catchment-level data for Alaska, local floodplains were delineated using Thiessen polygons based on the vertices of the stream segments in the Best Resolution NHD (USGS, 2023d). In this case, the Tiessen polygons represent the areas of influence around the individual stream segments where any location inside the polygon is closer to the vertices of the stream segment than to any other stream segment vertices, rather than the actual water draining areas, a reasonable assumption in the absence of detailed catchment boundaries (e.g., Macfarlane et al., 2018).

The local floodplains were finally merged into a single floodplain layer. Taken together, the final floodplain layer comprised more than 2.1 million individual floodplains over the entire U.S., representing a total of 256,762,131 acres (218,628,960 acres for the contiguous U.S.). For reference, we have also included the 100-year floodplain, digitized as part of the FEMA National Flood Hazard Layers (Zones A/AE; FEMA, 2025).

4. Mechanisms and extent of floodplain protection

Recognizing that floodplains lay at the nexus between freshwater and terrestrial systems and can thus be afforded protection through various means (Abell et al., 2007; Acreman et al., 2020; Higgins et al., 2021), in the NFFA, we considered seven broad categories of protection, each composed of one or more individual protection mechanisms (Table 1). Datasets were compiled through the curation of freshwater specific datasets (several digitized for the first time for this assessment) and various protected area databases. The overall workflow and mechanisms are summarized in Figure 1.

To estimate the extent of floodplain protection across the U.S., we performed a pairwise intersection between the protected areas and the local floodplain polygons (Figure 4). To do so, we first applied buffers to all the protected areas, using 50 m for linear-shaped polygons (such as wild and scenic river corridors and riparian buffers) and 100 m for other polygon-shaped protected areas, to circumvent potential issues arising from minor misalignments between the floodplain and the protected area polygons. We then developed a floodplain layer, estimating the area of the floodplains intended for protection by each mechanism of protection.

We summarized protection by calculating the floodplain area afforded protection according to each protection mechanism at the watershed and state scales. For the watersheds, we adopted the HUC 12 scale (Hydrologic Unit Code 12) from the Watershed Boundary Dataset (NHDPlus v2.1 for the contiguous U.S. and Hawaii and the National Hydrography Dataset Best Resolution for the state of Alaska), corresponding to local sub-watersheds that capture tributary systems (approximately 97,000 nationwide). The extent of river protection was reported as a percentage of the total floodplain area in each watershed or state, accounting for the fact that floodplain extent may vary spatially. We note that the relationship between individual floodplains and watersheds was determined based on the local catchment identities associated with each floodplain, rather than the exact boundaries of the watersheds. Likewise, the relationships between the individual floodplains and the states were determined based on the coordinates of the centroids of the individual floodplains rather than the exact boundaries of the states. Finally, we note that several designation types can be assigned to the same local floodplain and thus the sum of the extent of protection across mechanisms in a given watershed or state can exceed 100%.

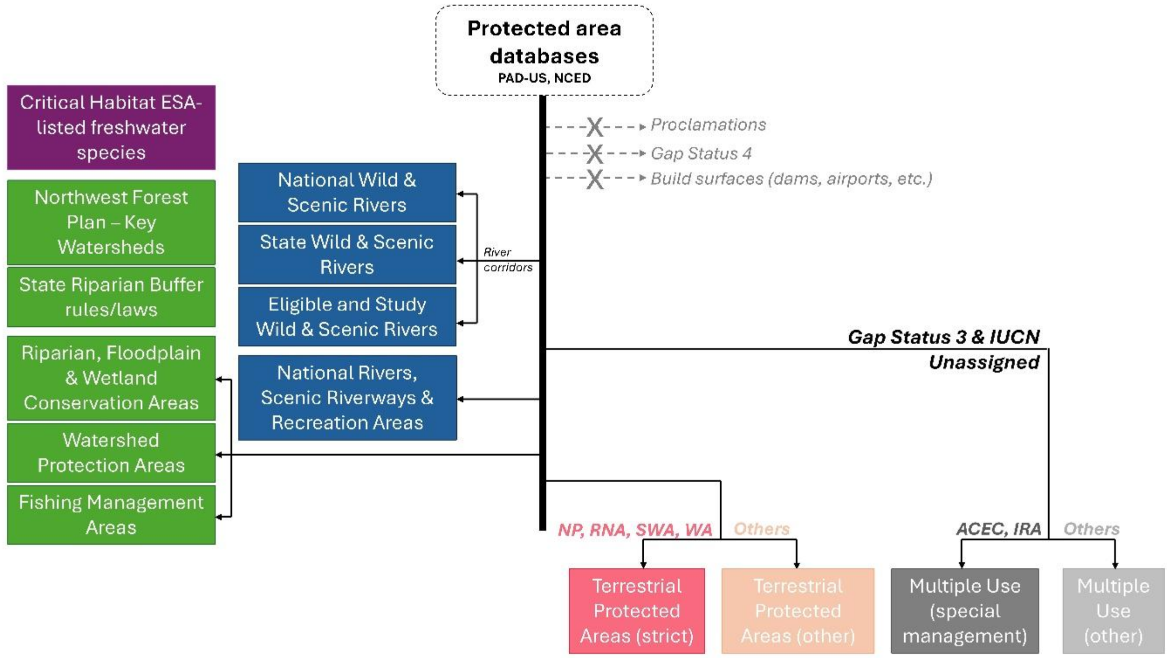

Figure 1. Overview of the workflow and mechanisms of river protection considered in the *National Functional Floodplains Assessment:* river conservation [blue], riparian and floodplain conservation [green], ESA-listed endangered freshwater species critical habitat [magenta], terrestrial protected areas (strict) [pink], terrestrial protected areas (other) [beige], multiple land use (special management) [dark grey], and multiple land use (other) [grey]. Abbreviations: International Union for Conservation of Nature (IUCN), Areas of Critical Concern (ACEC), Inventoried Roadless Areas (IRA), National Parks (NP), Research Natural Areas (RNA), State Wilderness Areas (SWA), Wilderness (and study) Areas (WA).

Table 1. Mechanisms of river protection included in the *National Functional Floodplains Assessment*.

Protection category	Protection mechanism	Source
River conservation		
	National wild and scenic rivers	Bonsall et al. (2016); BLM (2022a); BLM (2022b); BLM (2023a); BLM (2023b); BLM (2023c); USFS (2017); USFS (2022a)
	Eligible and study wild and scenic rivers	USFS (2022b); USFS (2022c)
	State wild and scenic rivers	This study
	Scenic riverways, national rivers, and recreation areas	PAD-US (USGS 2022), NCED (Ducks Unlimited & The Trust for Public Land 2023)
Riparian and floodplain conservation		
	Riparian reserves - Northwest Forest Plan	Dunham et al. (2023)
	State riparian buffers	This study
	Watershed protection areas	PAD-US (USGS 2022), NCED (Ducks Unlimited & The Trust for Public Land 2023)
	Riparian, floodplain, and wetland conservation areas	PAD-US (USGS 2022), NCED (Ducks Unlimited & The Trust for Public Land 2023)
	Key Watersheds - Northwest Forest Plan	REO (2002)
Endangered species critical habitat		
	Critical habitat for ESA-listed freshwater-dependent species	USFWS (2023a); USFWS (2023b)
Terrestrial protected areas		
	Terrestrial protected areas (strict). E.g., Research Natural Area, Wilderness (and study) Area, State Wilderness, National Park	PAD-US (USGS 2022), NCED (Ducks Unlimited & The Trust for Public Land 2023)
	Terrestrial protected areas (other). E.g., National Wildlife Refuge, National Recreation Area, State Conservation Area, Conservation Easement, Private Conservation, State Park	PAD-US (USGS 2022), NCED (Ducks Unlimited & The Trust for Public Land 2023)
Multiple land use		
	Multiple land use (special management). E.g., Inventoried Roadless Areas, Area of Critical Environmental Concern	PAD-US (USGS 2022), NCED (Ducks Unlimited & The Trust for Public Land 2023)
	Multiple land use (other). E.g., National Forest, National Grassland, Conservation Easement, Forest Stewardship Easement, Private Conservation, Local Recreational Area, Local Park	PAD-US (USGS 2022), NCED (Ducks Unlimited & The Trust for Public Land 2023)

5. Computation of the Floodplain Alteration Index

Fundamental to the concept of functioning floodplains are the attributes of hydrologic connectivity and habitat integrity where: (1) lateral connectivity to adjacent streams of rivers is maintained to allow the exchange of material and energy, (2) natural flow regime of the adjacent stream or river is preserved to allow for periodic inundation of the floodplain, (3) habitat is intact to accommodate for spatiotemporal dynamics of inundation and other fluvial geomorphic processes to occur (American Rivers, 2016; Opperman et al., 2010; Tockner & Stanford, 2002; Ward et al., 1999). Following this framework, the degree of alteration of each individual floodplain was assessed with respect to three complementary components: lateral connectivity alteration, river flow alteration and degree of human development. Each component was estimated using one or more indicators, which were subsequently aggregated into an overall floodplain alteration index. Due to data availability constraints, the underlying datasets used to estimate these three indicators, and therefore the overall floodplain alteration index necessarily differed between the contiguous U.S., Alaska and Hawaii (Table 2).

Lateral connectivity alteration

For the contiguous U.S., alteration of lateral connectivity was estimated using two indicators. First, we estimated the percentage of the local floodplain area that was either no longer connected or more likely to be inundated due to artificial levee construction, based on the spatial classification provided in Knox et al. (2022a). To do so, we split the floodplain layer provided in Knox et al. (2022a) into local floodplains based on the catchment areas associated with each stream segment of the NHDPlus v2.1 (see 3. *Floodplain extent*) and estimated the ratio between the areas classified as disconnected or artificially connected over the total floodplain area (including the agreement areas), then expressed as a percentage. Second, we estimated the linear density of artificial levees within local floodplains, using both the inventoried levees included in the National Levees Database (USACE, 2024) and the potential non-inventoried levees identified by Knox et al. (2022b) using a machine learning algorithm. To do so, we clipped the original levee polygons to the individual floodplain boundaries and estimated the ratio of the levee's length to the individual floodplain area, then expressed it in feet per acre. The two indicators were then rescaled between 0 and 1 and aggregated using a fuzzy sum, that is, an increasing linear combination function of the three components, so that the index is always as great as the maximum value of the components but can never exceed 1.0 (Theobald, 2013). The lateral connectivity index was subsequently expressed between 0 and 100, where values of 100 reflect a high degree of lateral disconnection. For Alaska and Hawaii, we only considered the rescaled linear density of artificial levees from the National Levees Database, noting that the alteration of lateral connectivity may thus be underestimated for these states.

River flow alteration

For the contiguous U.S., in-stream flow alteration was estimated using the Hydrologic Alteration Index (HAI) developed by McManamay et al. (2022) for the stream segments of the NHDPlus v2.1, which is a multivariate cumulative index of flow alteration based on 41 hydrologic statistics summarizing modeled changes to the magnitude, frequency, duration, timing, and rate of change of flow events and varying between 0 (no flow alteration) to 1 (highest flow alteration). HAI was not estimated by McManamay et al. (2022) for outside the contiguous U.S. Therefore, for Alaska, we used the Connectivity Status Index (CSI) developed by Grill et al. (2019) that estimates the extent to which river connectivity is maintained based on a set of 6 pressure indicators mainly related to the degree of flow regulation and fragmentation by anthropogenic barriers in the river channel (i.e., rivers with a CSI > 95 % are considered free flowing). As the underlying stream network used to develop the CSI differs from the one used in this assessment, we computed the mean CSI value within a 150 m buffer around each local floodplains and expressed the index as (100 - meanCSI)/100 so that the index varies between 0 (no alteration of longitudinal connectivity) to 1 (high alteration of longitudinal connectivity). Although the HAI and CSI are conceptually different, the CSI is likely to capture the complex nature of threats acting along river channels that ultimately lead to alteration of different facets of natural flow regimes (McManamay et al. 2022), an expectation supported by the significant association found between the two indices within the contiguous U.S. (correlation = 0.36 between HAI and 100 - meanCSI)/100). The river flow alteration index was subsequently expressed as a value between 0 and 100, where index values of 100 reflect a high degree of flow alteration. No indicator of river flow alteration was included for Hawaii.

Human development

The degree of human development within local floodplains for the contiguous U.S., Alaska and Hawaii was estimated using the global Human Modification Index (circa 2017) version 1.5 at 300-m resolution (gHMI; Theobald et al., 2023). The gHMI is an integrative index of human modification that considers the spatial extent and intensity of various threats to ecosystems, including urban or agricultural land use change, extractive activities, infrastructure developments, reservoirs and air pollution, which varies between 0 (no spatial footprint of human activities, natural) to 1 (maximum spatial footprint of human activities, unnatural) (Theobald et al., 2020). To do so, we estimated the mean gHMI within each local floodplain, after resampling the data at 30-m resolution using a bilinear interpolation to match the original resolution of the floodplain layer. The human development index was subsequently expressed between 0 and 100, where index values of 100 reflect a high degree of human development within the floodplain.

Floodplain alteration index

Aggregation of each component (lateral connectivity alteration, river flow alteration and human development) into an overall floodplain alteration index was done using a fuzzy sum, so that the three components were equally weighted in the floodplain alteration index. Covariations among the three components were low to moderate (correlation coefficient: 0.06 between lateral connectivity alteration and river flow alteration, 0.08 between lateral connectivity and human development and 0.55 between river flow alteration and human development), indicating that they effectively captured different facets of floodplain alteration. The floodplain alteration index was subsequently expressed between 0 and 100, where index values of 100 indicating a high degree of floodplain alteration. In interpreting the results, we considered the following categories of the floodplain alteration index: 0 – 25: low alteration, 25 – 50: moderate alteration, 50 – 75 high alteration, and 75 – 100: very high alteration.

These indices were then summarized at the watershed scale (HUC 12, see *4. Mechanisms and extent of floodplain protection*), using a weighted mean based on the area of the individual floodplains associated with a given watershed.

Table 2. Data source for the different indicators of floodplain alteration considered in this assessment for the contiguous U.S. [CONUS], Alaska and Hawaii.

Indicators of floodplain alteration:			
Component	Indicator	Spatial extent	Source
Lateral connectivity alteration			
	Percentage of floodplain modified by artificial levees	CONUS	Knox et al. (2022a)
	Linear density of inventoried artificial levees	CONUS, Alaska, Hawaii	National Levees Database (USACE, 2024)
	Linear density of non-inventoried artificial levees	CONUS	Knox et al. (2022b)
River flow alteration			
	Hydrologic Alteration Index (HAI)	CONUS	McManamay et al. (2022)
	Connectivity Status Index (CSI)	Alaska	Grill et al. (2019)
	No indicator	Hawaii	–
Human development			
	global Human Modification Index (gHMI)	CONUS, Alaska, Hawaii	Theobald et al. (2023)

6. Informing the prioritization of floodplain protection and restoration

To provide context for future prioritization of protection and restoration activities, we included a set of additional variables that capture some of the major values and threats to floodplains. These variables were summarized at the watershed-level to match the scale of the protection and alteration assessment. Due to data availability constraints, some of these variables are provided only for the contiguous U.S. Variable selection was informed by multiple discussions with the American Rivers team. These variables are briefly described below and in Table 3.

Floodplain threats

The components of the floodplain alteration index were complemented by three additional indices.

(1) *River-floodplain disconnection* was estimated using the sum of the area of the floodplains within each watershed (i.e., HUC 12) that was estimated to be no longer connected because of artificial levee construction from Knox et al. (2022a).

(2) *River-floodplain artificial inundation* was estimated using the sum of the area of the floodplains within each watershed (i.e., HUC 12) that was estimated to be now artificially inundated because of artificial levee construction from Knox et al. (2022a).
(3) *Density of artificial levees* was estimated using the ratio of the levee's length to the individual floodplain area (considering both inventoried and potential non-inventoried levees; see *5. Computation of the Floodplain Alteration Index*) for each individual floodplain. Estimates were then obtained by averaging the floodplain-specific values across watersheds (i.e., HUC 12) using a weighted mean based on the area of the individual floodplains.

Flood risk

We selected the following riverine flood hazard indices from the National Risk Index (version March 2025; FEMA, 2023), which were reapportioned from census tracts to watersheds (i.e., HUC 12) based on the percentage of areal overlap.

(1) *Flood risk index*, estimating a community's overall risk from flooding based on expected economic losses, social vulnerability, and community resilience in comparison to all communities in the country, where values of 100 reflect high risk.
(2) *Social vulnerability*, estimating the social, economic, demographic, and housing characteristics of a community that influence its ability to prepare for, respond to, cope with, recover from, and adapt to environmental hazards in comparison to all communities in the country, where values of 100 reflect high vulnerability.
(3) *Flooding frequency*, estimating the annualized flood frequency expressed as the observed frequency or probability of 100-year riverine flooding occurrence per year.

Aquatic biodiversity

(1) *Native aquatic species* were estimated as the number of native freshwater species among 1,510 animals, including fish, amphibians, crayfish, mollusks, and turtles, within each HUC 12 based on the International Union for Conservation of Nature's (IUCN) Red List spatial database (Panlasigui et al. 2018, USEPA 2024).
(2) *Imperiled species* was estimated as the number of freshwater-dependent species classified as critically imperiled (categorized by NatureServe as "G1"), imperiled ("G2"), and ESA-listed (i.e., species listed as Endangered or Threatened under the Endangered Species Act) among plants, vertebrates and invertebrates (Nature Serve Network 2024) occurring within riparian areas and along river corridors. To do so, we extracted the maximum number of modelled imperiled species within each HUC 12 intersecting either with the riparian areas associated with each stream segment (Abood et al. 2022), or if a given segment did not display a riparian area with the stream segment.

River Protection

(1) *Viable river protection* was estimated as the percentage of river length in a given watershed classified as being afforded protection at a level deemed viable according to the classes of Protected River Index (PRI) Comprehensive, Effective and Limited (CSP 2025).

Table 3. Contextual variables summarized at the watershed (HUC 12) level.

Category	Variable	Source
Floodplain alteration		
	River-floodplain disconnection (acres)	Knox et al. (2022a)
	River-floodplain artificial inundation (acres)	Knox et al. (2022a)
	Density of artificial levees (feet per acre)	USACE (2024); Knox et al. (2022b)
	River flow alteration (0-100)	McManamay et al. (2022); Grill et al., (2019)
	Human development (0-100)	Theobald et al. (2023)
Flood risk	Flood risk index (0-100)	FEMA (2023)
	Social vulnerability (0-100)	FEMA (2023)
	Flood frequency (number per year)	FEMA (2023)
Aquatic biodiversity		
	Native aquatic species (number of animal species)	EPA (2024a)
	Imperiled species (number of plant and animal species within riparian areas and along river corridors)	Abood et al. (2022); Nature Serve Network (2024)
River protection		
	Viable river protection (%)	CSP (2025)

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