Standard Modular Hydropower Resources Webinar

https://hydropower.ornl.gov/smh

Thursday September 6th, 2018

ORNL is managed by UT-Battelle
for the US Department of Energy

OAK RIDGE
National Laboratory

Message from DOE WPTO

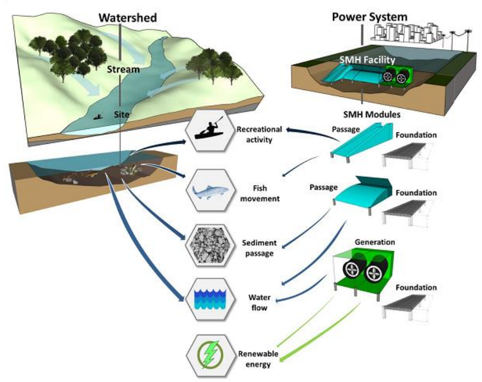
Welcome

Ground rules for the call

Note: ORNL is not authorized to answer any questions regarding Funding Opportunity Announcement DE-FOA-0001836: INNOVATIVE DESIGN CONCEPTS FOR STANDARD MODULAR HYDROPOWER AND PUMPED-STORAGE HYDROPOWER on this call. For specific questions on this topic, please email WPTOFOA1836@ee.doe.gov.

Webinar Agenda

Introduction/Motivation



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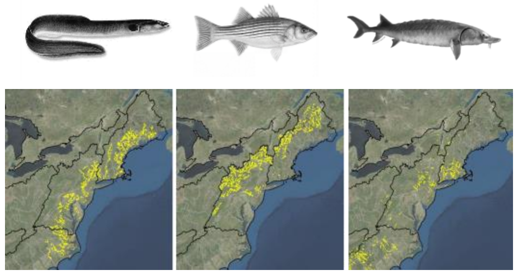
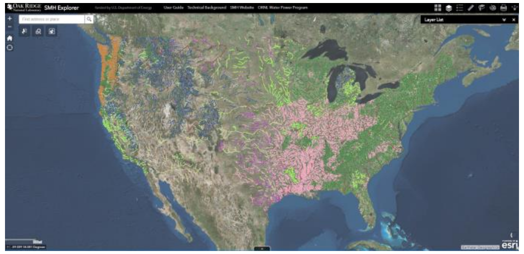
Site Classification



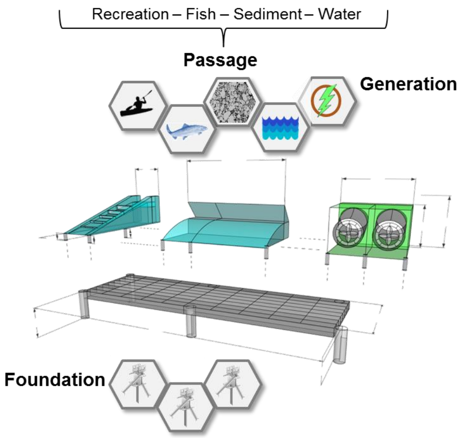
10 min

SMH Explorer



15 min

Design Envelope



15 min

Q&A

15 min

Standard Modular Hydropower Motivation

We are at a crossroads with respect to development of new low-head small hydropower facilities:

Benefits of small hydro

Renewable and carbon free energy	Dependable, reliable generating capacity	Local and national economic investment	Long asset life	Avoided greenhouse gas emissions	Avoided water withdrawals for electricity	Recreation opportunities

Environmental impacts and ecosystem complexity

Site-specific design, site-specific impacts, long and uncertain regulatory process

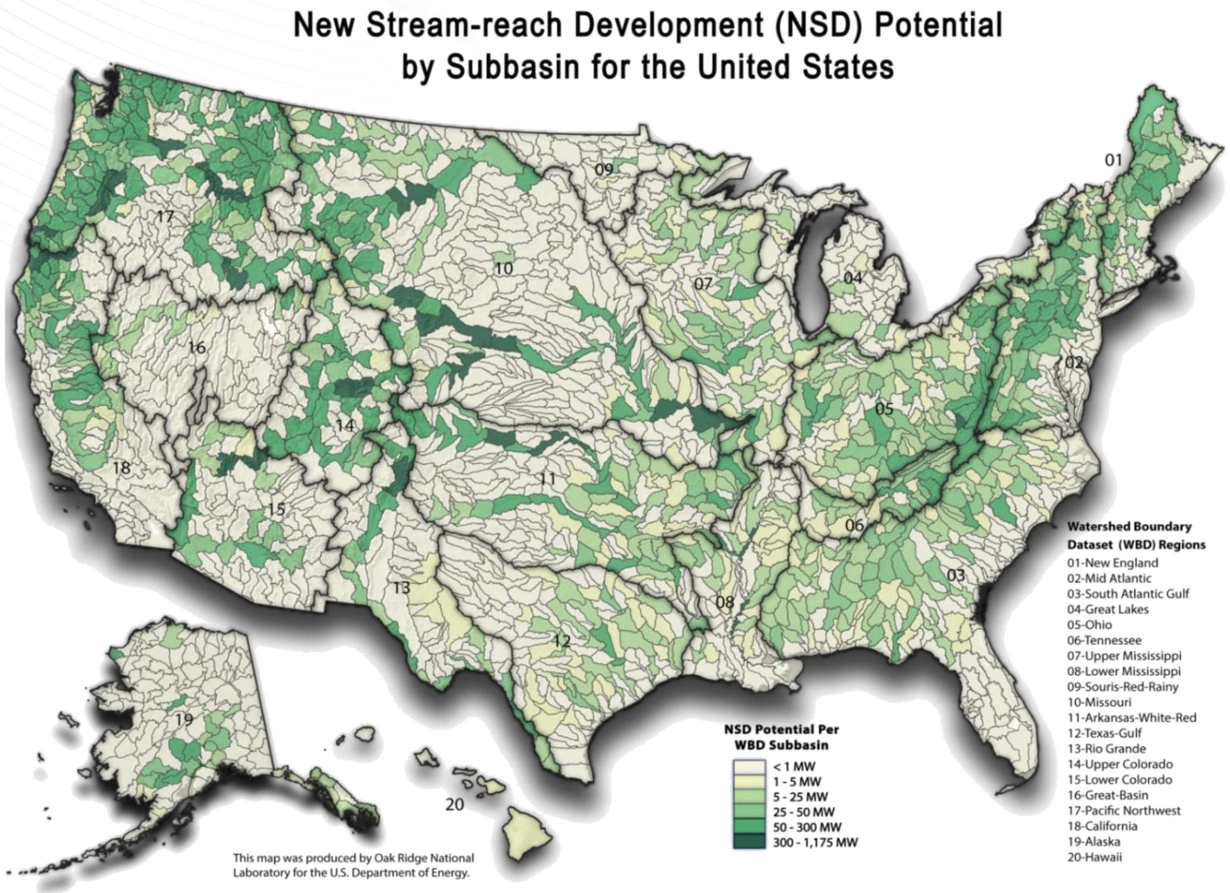
Difficult project economics and renewable energy competition

High capital costs and competition from rapid deployment of new low-cost wind and solar capacity

Standard Modular Hydropower Motivation

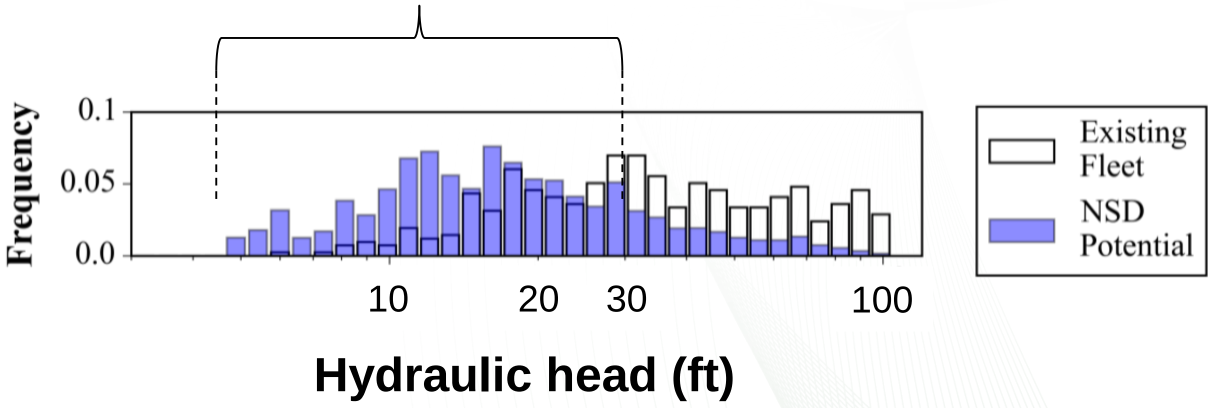
Theoretical resource potential for new small hydropower

29 GW of technical cumulative NSD potential at 10,000 sites
with less than 10 MW of installed capacity each



https://nhaap.ornl.gov/nsd

Majority of NSD sites are **low-head** (< 30ft)
compared to existing fleet



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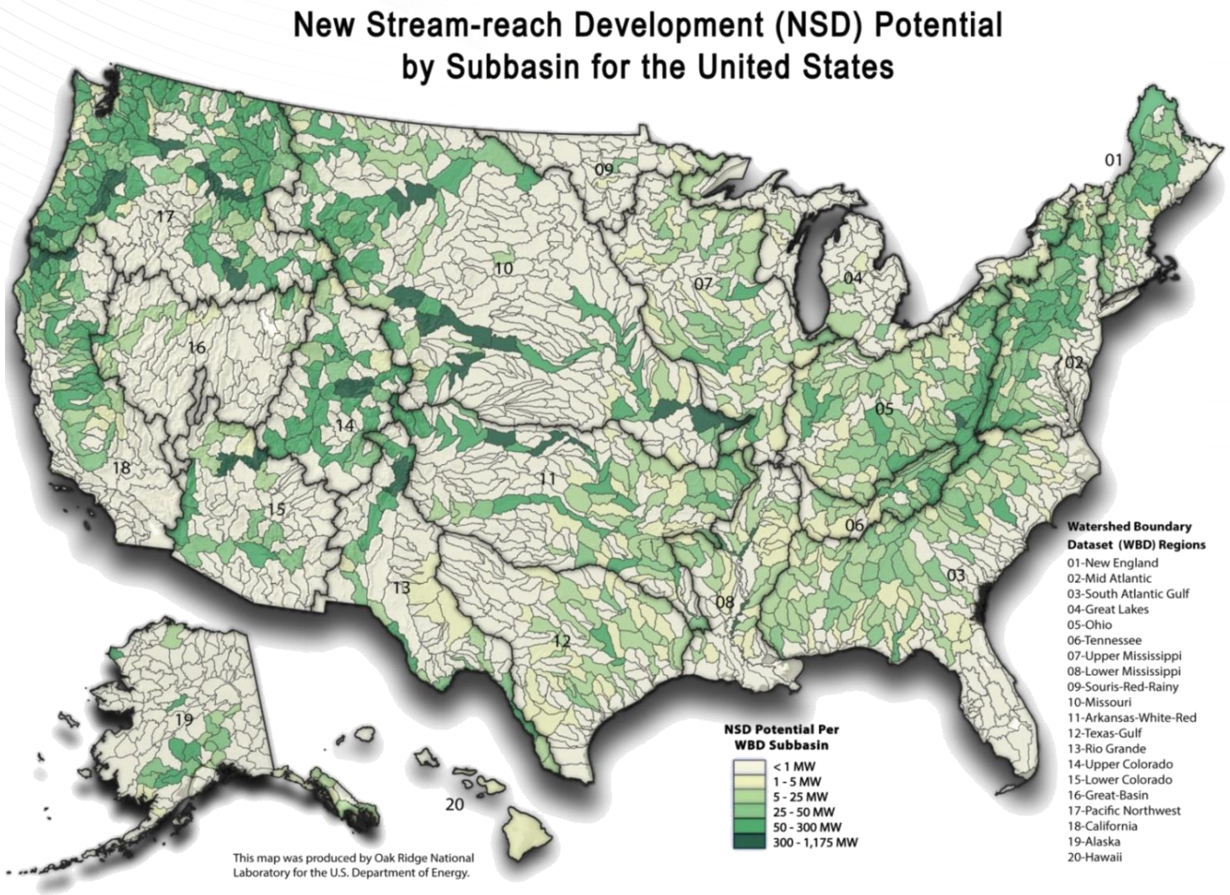
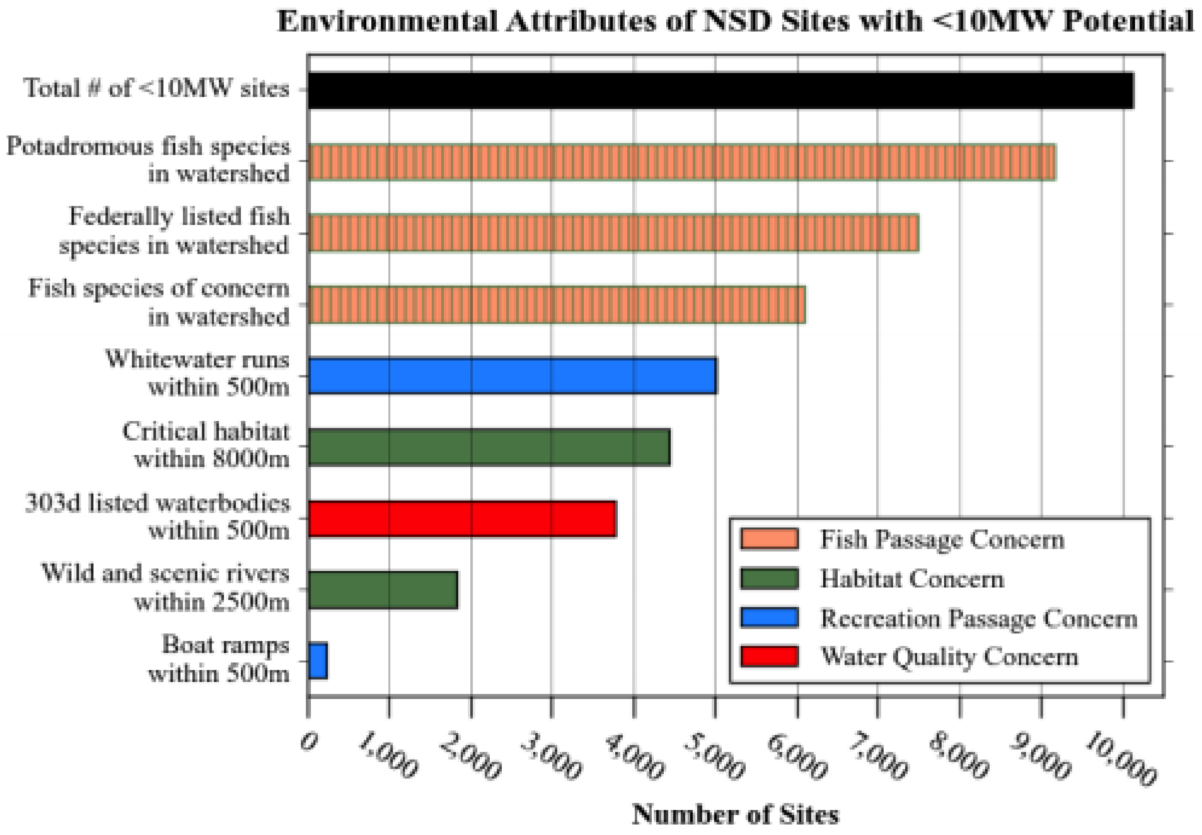


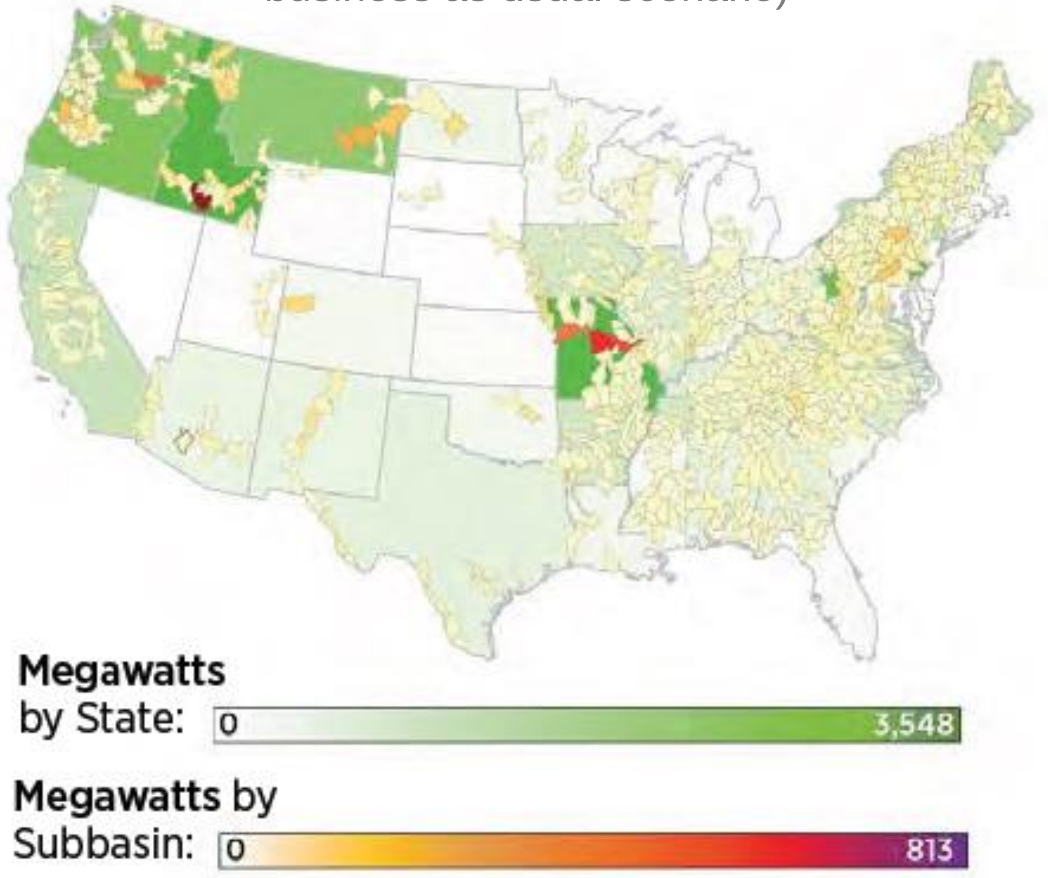


https://nhaap.ornl.gov/nsd

Standard Modular Hydropower Motivation

Hydropower Vision Report NSD modeling scenario

With advanced technology and solutions to environmental considerations, 17.2 GW of new hydropower could be competitively deployed by 2050 (15.5 GW greater than business as usual scenario)



https://www.energy.gov/eere/water/articles/hydropower-vision-new-chapter-america-s-1st-renewable-electricity-source

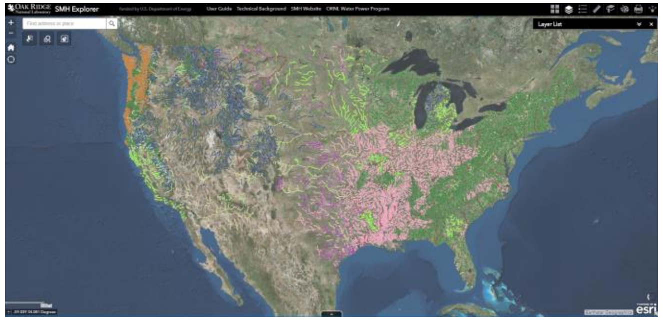
Standard Modular Hydropower Motivation

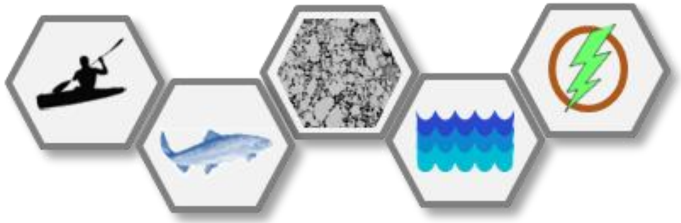
*Seeking to stimulate innovative designs that incorporate **standardization**, **modularity**, and **environmental compatibility** as enabling design principles of small, low-head hydropower facilities*

Standardization:
Standard siting methods, designs and technologies, project review, regulatory pathways, construction sequencing, and O&M to reduce site specificity and project costs.

Modularity:
The physical organization of a hydropower facility into generation, passage, and foundation modules assembled to deliver energy and environmental benefits at many different sites.

Environmental Compatibility:
Facilities sited and operated as coupled human-natural systems to minimize disturbances to landscape features, water quantity, connectivity, geomorphology, water quality, and biota.





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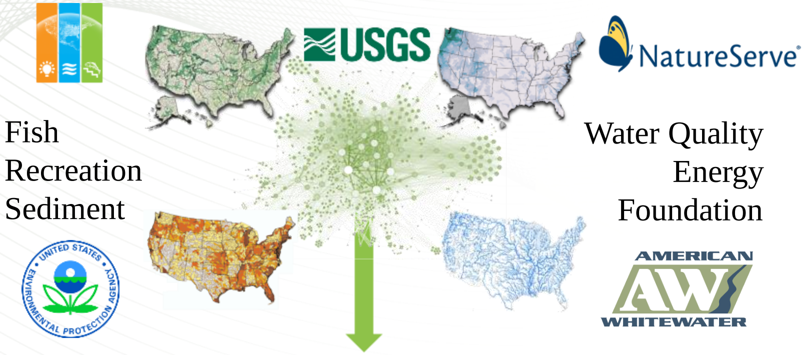
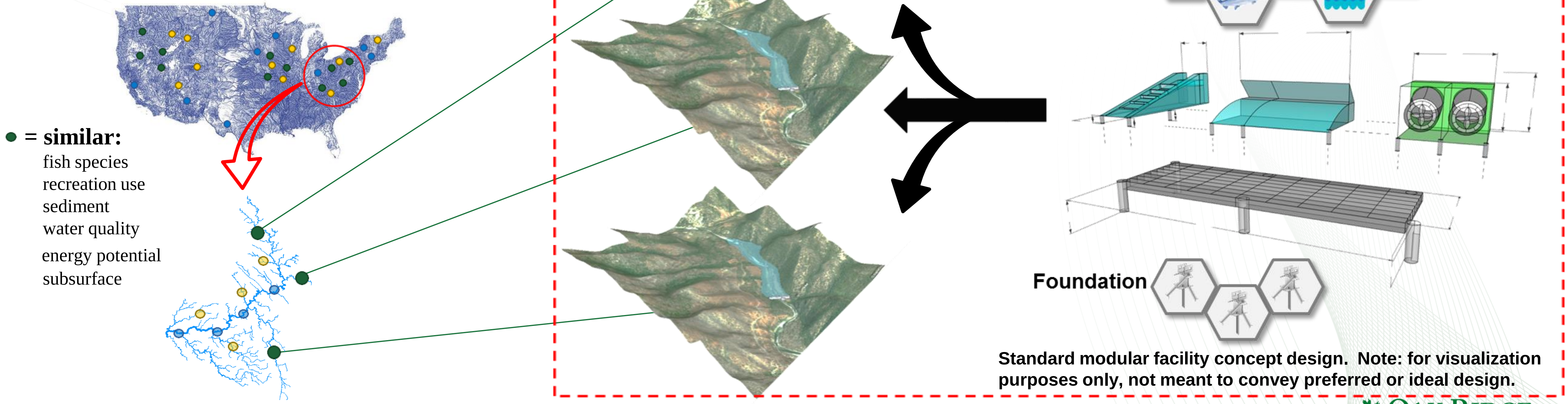
Standard Modular Hydropower Concept

Data aggregation and site classification



Clusters of similar sites

Sites in a cluster have common design requirements, may be developed with a suite of standard modular generation, passage, and foundation technologies

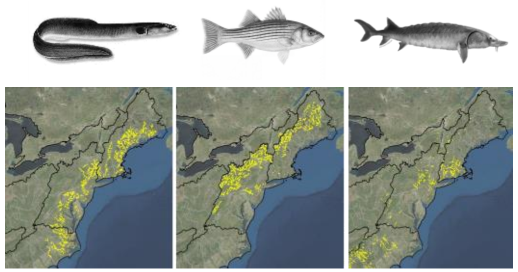


Webinar Agenda

Introduction/Motivation

5 min

Site Classification



10 min

SMH Explorer

15 min

Modular Design

15 min

Q&A

15 min

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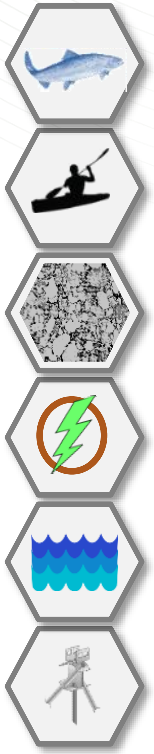
Site Classification

Objective: To group similar stream reaches into a finite number of clusters based on characteristics/variables that can be used to inform both need and design requirements for a module type.

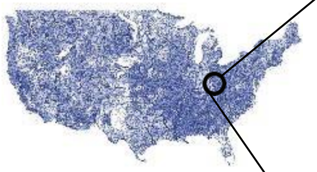
Classification for each module type



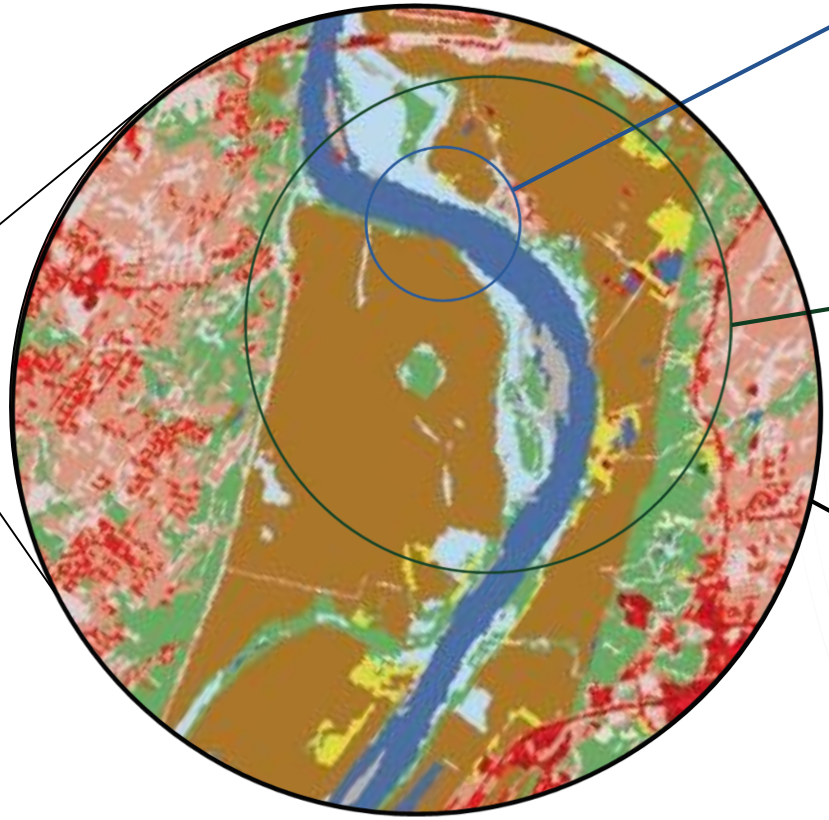
- Fish Passage
- Recreation
- Sediment
- Generation
- Water Quality
- Foundation

Classification Units

300,000+ NHD stream reaches with mean annual flow between 50 - 25,000 cfs



Single stream-reach (i.e., site)



Clustering Variables

In-stream
- Physical
  - Hydrology
  - Gradient
  - Geomorphology
- Biological
  - Species present

Landscape (local or regional)
- Land use
- Soil type
- Impervious surfaces
- Existing dams and mitigation

Geo-political
- Population density

Data sources for Site Classification (and SMH Explorer)

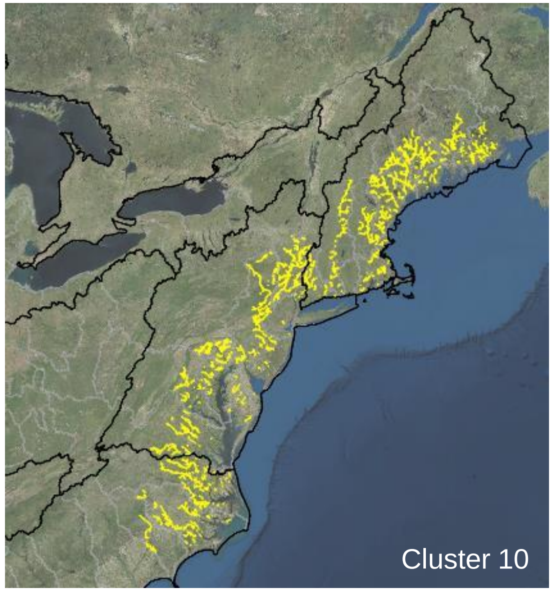
Dataset	URL
ORNL SMH	https://hydropower.ornl.gov/smh/
ORNL NSD	https://nhaap.ornl.gov/nsd
ORNL NPD	https://nhaap.ornl.gov/content/non-powered-dam-potential
ORNL Environmental Mitigation	https://nhaap.ornl.gov/environmental-mitigation
ORNL LandCast	http://www.pnas.org/content/112/5/1344
USGS NHDPlusV2	http://www.horizon-systems.com/nhdplus/NHDPlusV2_home.php
USGS WBD	https://nhd.usgs.gov/wbd.html
USGS WRD NSDI	https://water.usgs.gov/lookup/getgislist
USGS seismic hazard maps	https://earthquake.usgs.gov/hazards/hazmaps/
USGS geologic maps	https://mrdata.usgs.gov/geology/state/
StreamCat	https://www.epa.gov/national-aquatic-resource-surveys/streamcat
USEPA WQ data	https://www.epa.gov/waterdata/waters-geospatial-data-downloads
EIA	https://www.eia.gov/maps/layer_info-m.php
NLCD 2011	https://www.mrlc.gov/nlcd2011.php
MSU Dam metrics DB	https://www.sciencedirect.com/science/article/pii/S004896971730308X?via%3Dihub
Yale Climate Opinion Maps	http://climatecommunication.yale.edu/visualizations-data/ycom-us-2016/
NatureServe	http://www.natureserve.org/conservation-tools/data-maps-tools/
UTK Hydraulics and Sedimentation Lab	http://hsl.engr.utk.edu/
Delorme/ORNL	https://developer.garmin.com/datasets/overview
American Whitewater/ORNL	https://www.americanwhitewater.org/
National Rivers Inventory	https://www.nps.gov/subjects/rivers/data.htm

Example: Fish Passage Classification in Northeastern US

Fish passage need can be grouped according to stream gradient, migratory species presence, local presence of other barriers, stream network connectivity, etc.

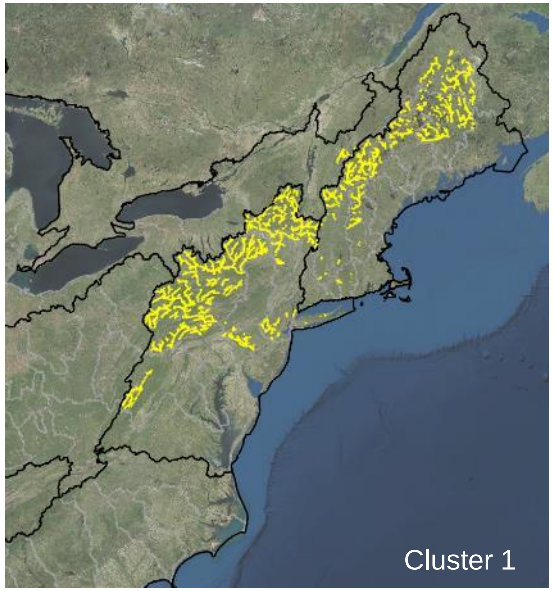
Clustering Variables

Mean annual **flow** (cfs)
Upstream network dam density per unit stream network length (#/100 km)
Downstream mainstem dam density per unit downstream mainstem length (#/100 km)
Percent of mitigation sites in the mitigation database within the HUC2 that had Tier 1 **fish passage mitigation required**
Number of **ocean-run sturgeon** species within the reach's HUC8 (count)
Number of **inland sturgeon/paddlefish** species within the reach's HUC8 (count)
Number of **ocean-run clupeid** species within the reach's HUC8 (count)
Number of **ocean-run eel/lamprey** species within the reach's HUC8 (count)
Number of **ocean-run salmonid** species within the reach's HUC8 (count)
Number of **inland salmonid** species within the reach's HUC8 (count)
Number of other **inland migratory species** within the reach's HUC8



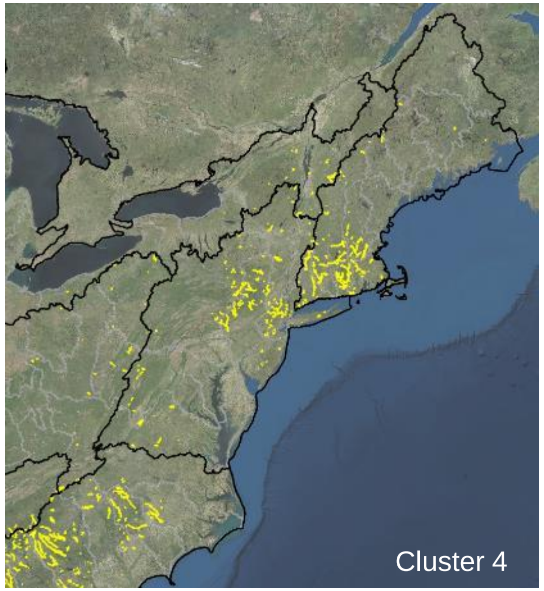
Common migratory species:
- Ocean-run anadromous species (clupeids, eels, sturgeons)

Common physical features:
- High flow
- Prevalent upstream dams



Common migratory species:
- Inland migratory trout

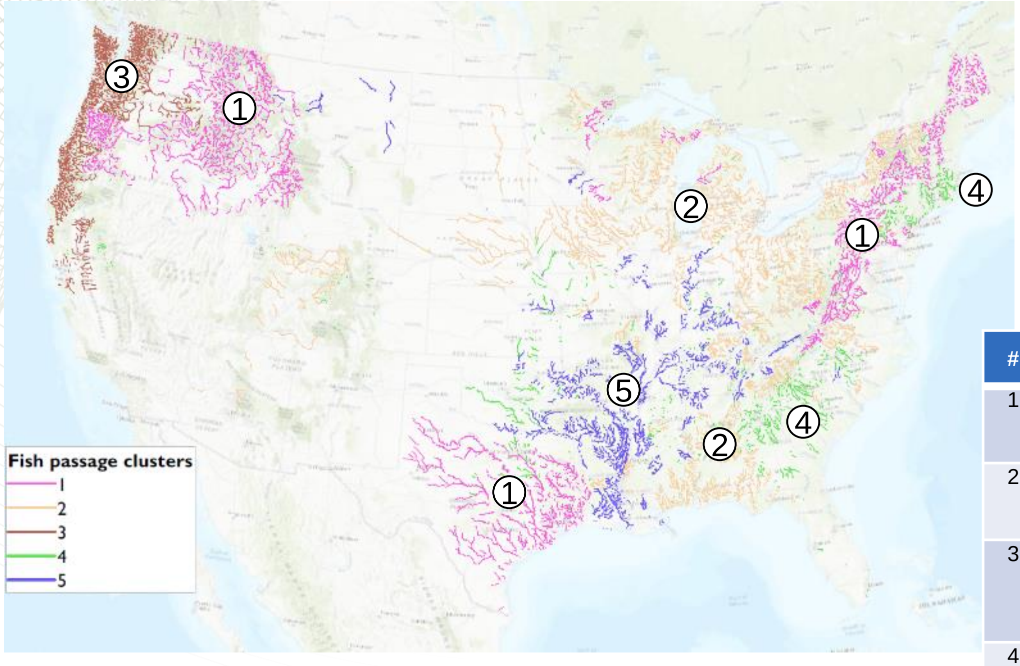
Common physical features:
- Moderate flow
- High passage mitigation at existing dams (i.e., mostly intake racks)

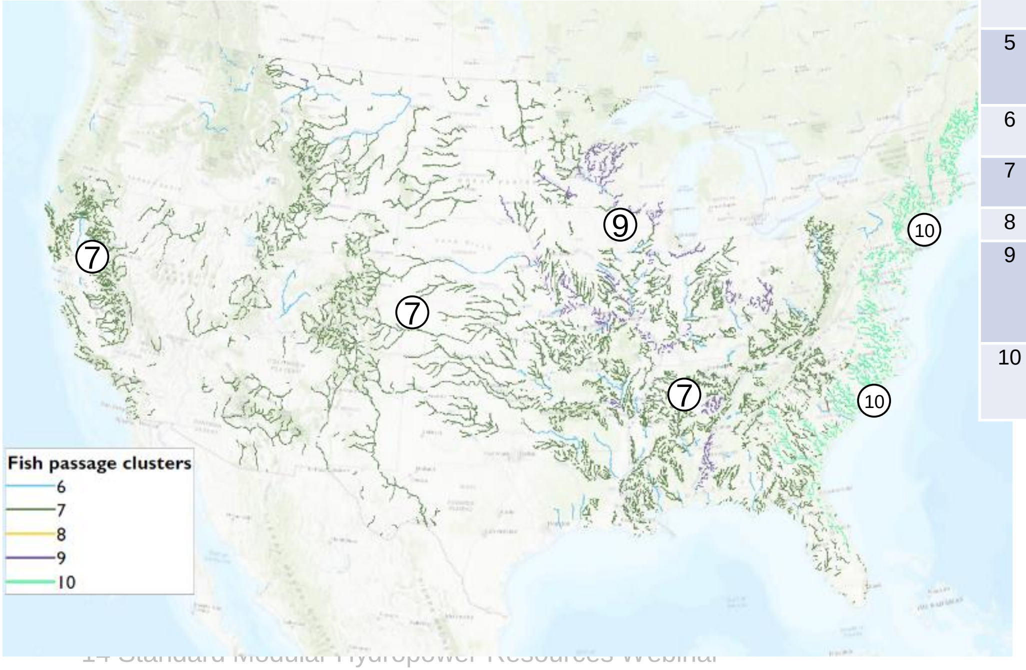


Common migratory species:
- Mixture of both inland and ocean-run migratory species (eels, clupeids, salmonids, sturgeon)

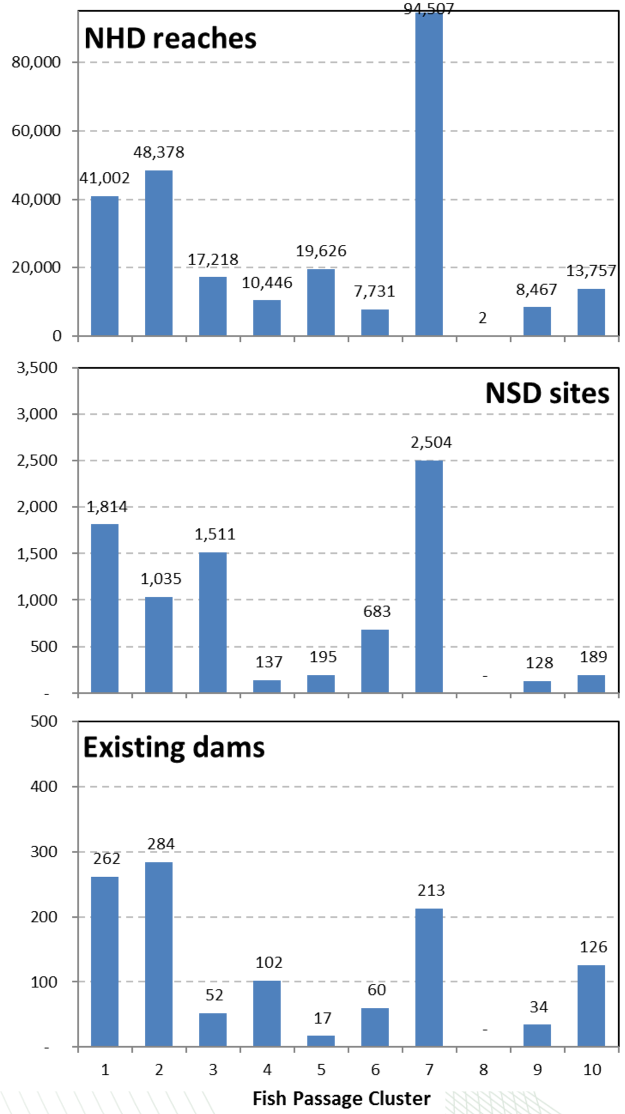
Common physical features:
- Low flow
- Prevalent upstream and downstream dams

Fish Passage





#	# Reaches	Defining characteristics	Locale
1	41,002	Potamodromous salmonids, high downstream dam count, high existing passage mitigation	Appalachia, Texas, Northwest
2	48,378	High other potamodromous species, low anadromous species	Great Lakes, upper Midwest, upper Ohio River, Gulf Coast
3	17,218	Anadromous salmonids, potamodromous salmonids, low upstream and downstream dam count, high existing passage mitigation, anadromous lampreys	Pacific Northwest
4	10,446	Some anadromous clupeids, high upstream and downstream dam count, low MAF	South central, New England
5	19,626	Low existing passage mitigation, low or absent salmonid presence, eels, low downstream dam count	Lower Mississippi River drainage
6	7,731	High MAF, inland sturgeon, and other inland species	Scattered nationally
7	94,507	Very low numbers of all major migratory species, low existing passage mitigation	Scattered nationally
8	2	–	–
9	8,467	Inland sturgeons and other inland potamodromous species, low downstream dam count, low existing passage mitigation, low anadromous species	Upper Mississippi River drainage
10	13,757	Anadromous clupeids, ocean-run sturgeons, eels, high upstream and downstream dam count	Atlantic Coast



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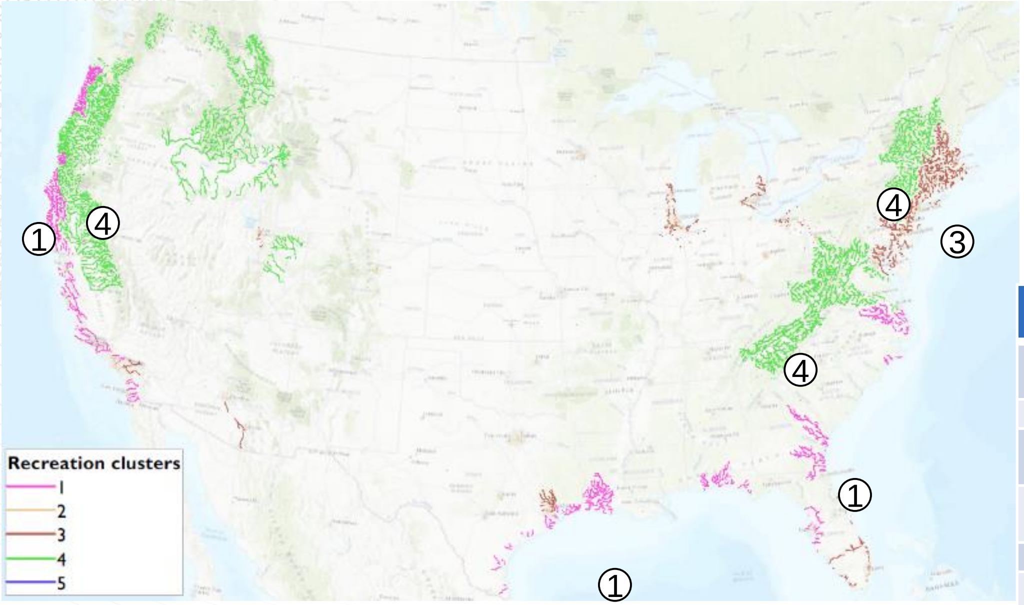
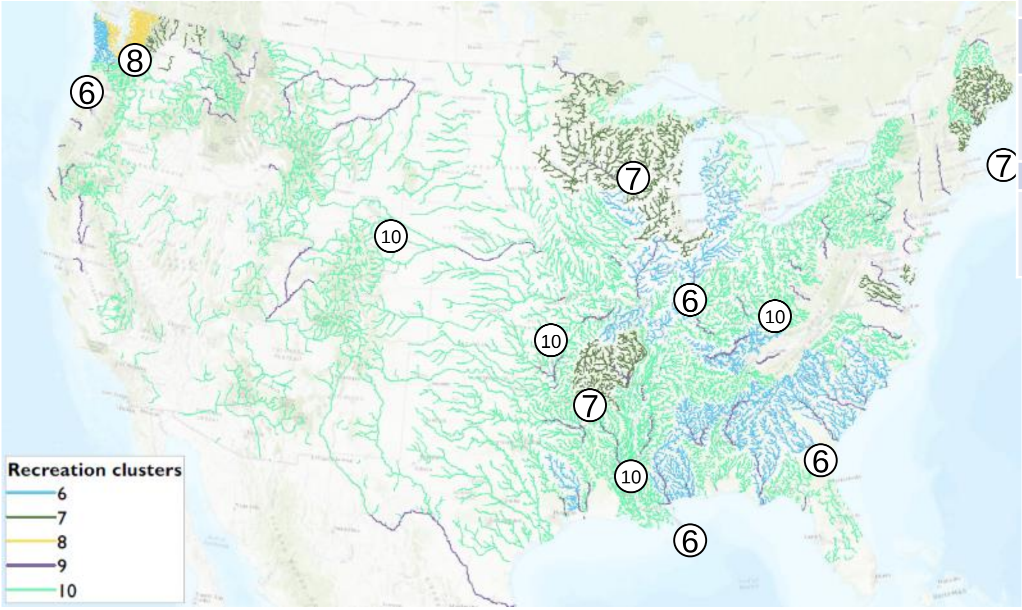
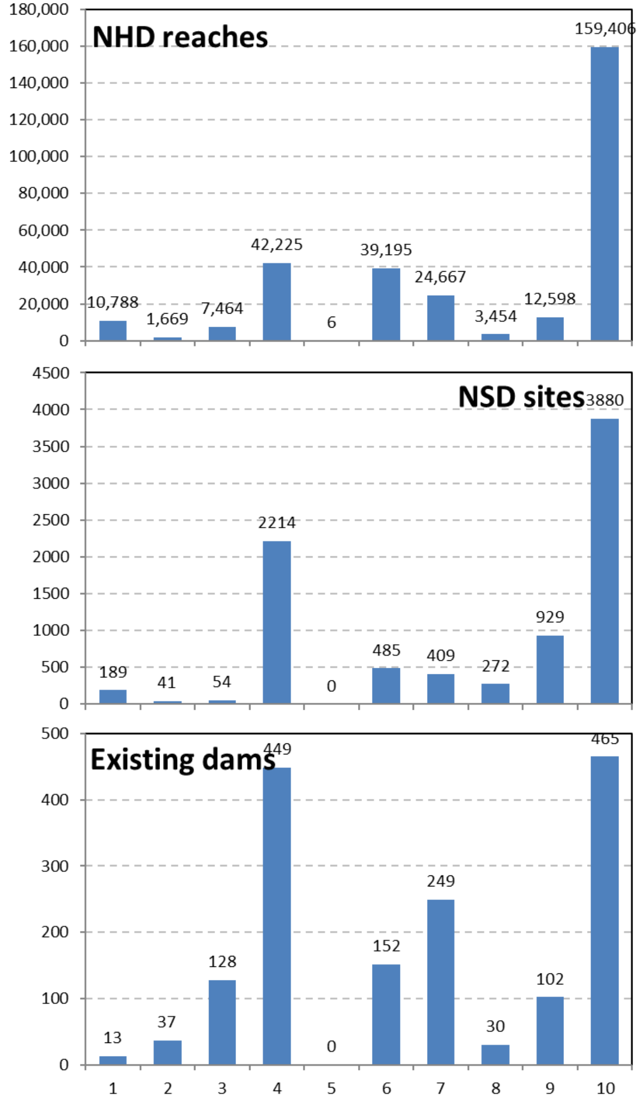
Recreation





#	# Reaches	Defining characteristics	Locale
1	10,788	Marine species fishing, small streams, limited boat access	Atlantic, Pacific, and Gulf coasts
2	1,669	Urban streams,	National
3	7,464	Suburban, small streams, coldwater fishing	National
4	42,225	High whitewater use, coldwater fishing	Appalachian, Sierras, and Rocky mtns
5	6		--
6	39,195	High recreational preservation value, low gradient	Mid-central, southeast, far northwest
7	24,667	Low gradient, high boat access, some whitewater	Maine, Wisc., Minn., and Ark.
8	3,454	Marine species fishing, high recreational preservation value, high whitewater use, high boat access, coldwater fishing	Puget Sound
9	12,598	Large rivers, low gradient	National
10	159,406	Rural, limited boat access, low gradient	Ohio R. and Mississippi R. valleys, eastern Great Lakes, Great Plains



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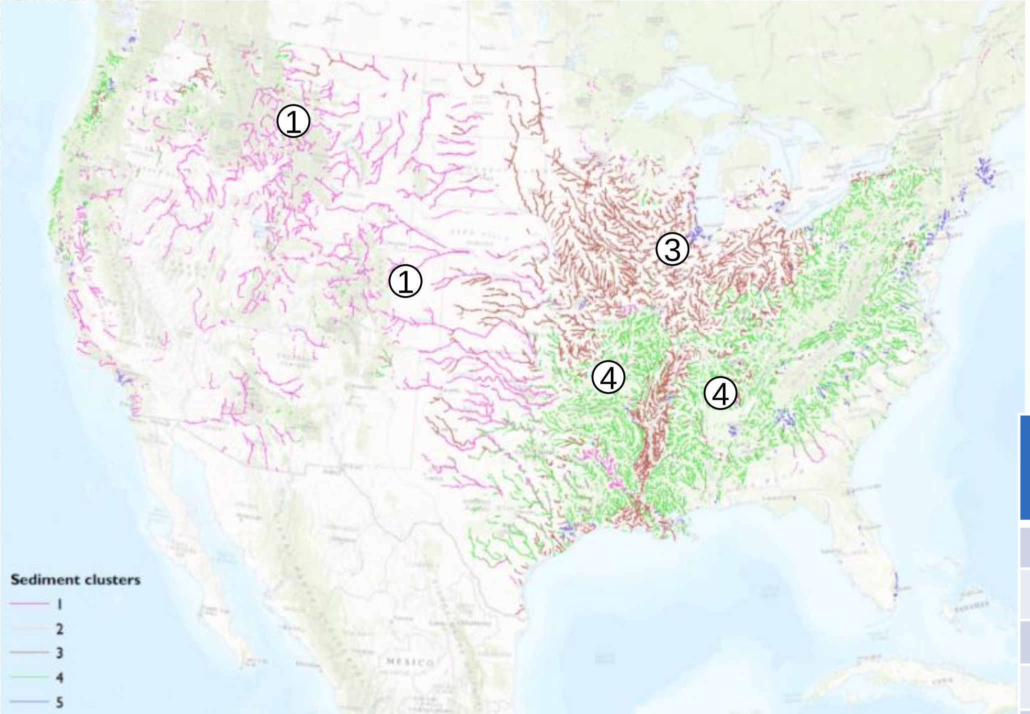
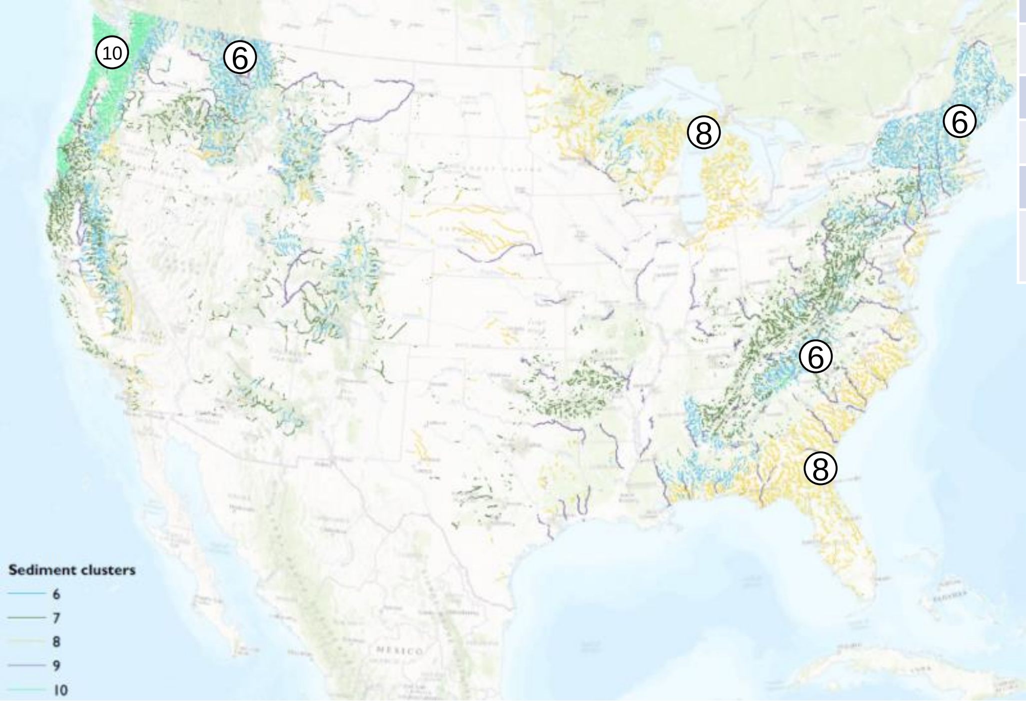
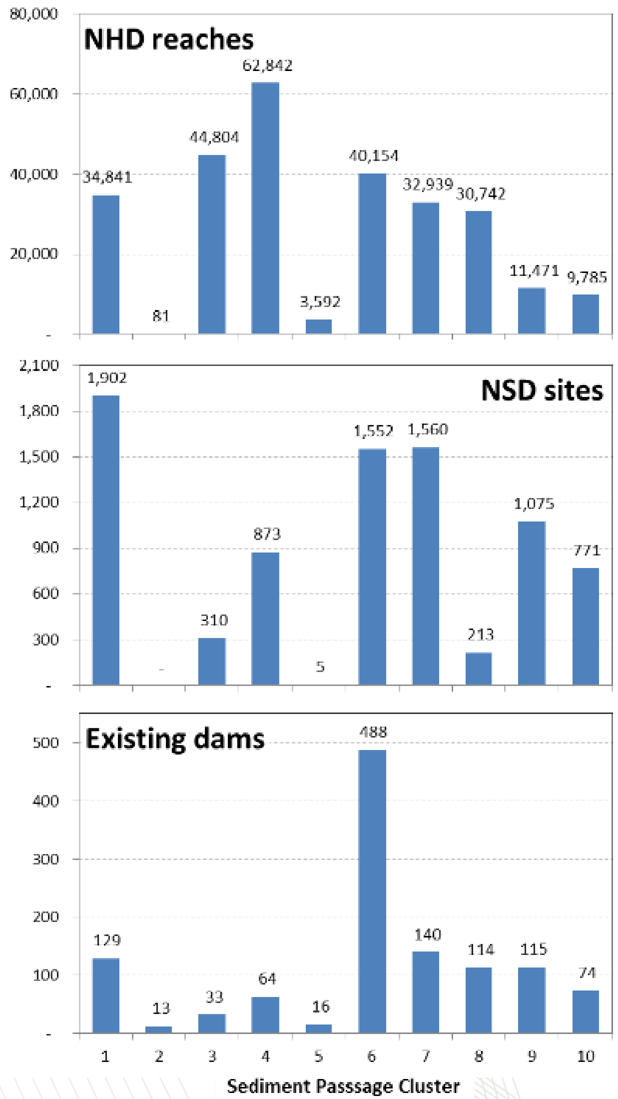
Sediment





#	# Reaches	Defining characteristics	Locale
1	34,841	Low runoff, variable flow	Mountain west and plains
2	81	Mod & steady flow, low ag, high runoff, high velocity	
3	44,804	Low velocity, clay	Upper midwest
4	62,824	Agricultural, slow, high erodibility, clay	Midsouth
5	3,592	Small streams, slow, urban	National
6	40,154	Forested, low ag	Northeast, northwest, Appalachians
7	32,939	Rocky streams, forested	National
8	30,742	Sandy, low erosion, slow	Southeast, Great Lakes
9	11,471	Large rivers, high velocity	National
10	9,785	Forested, low ag, high runoff, steady flow	Pacific northwest



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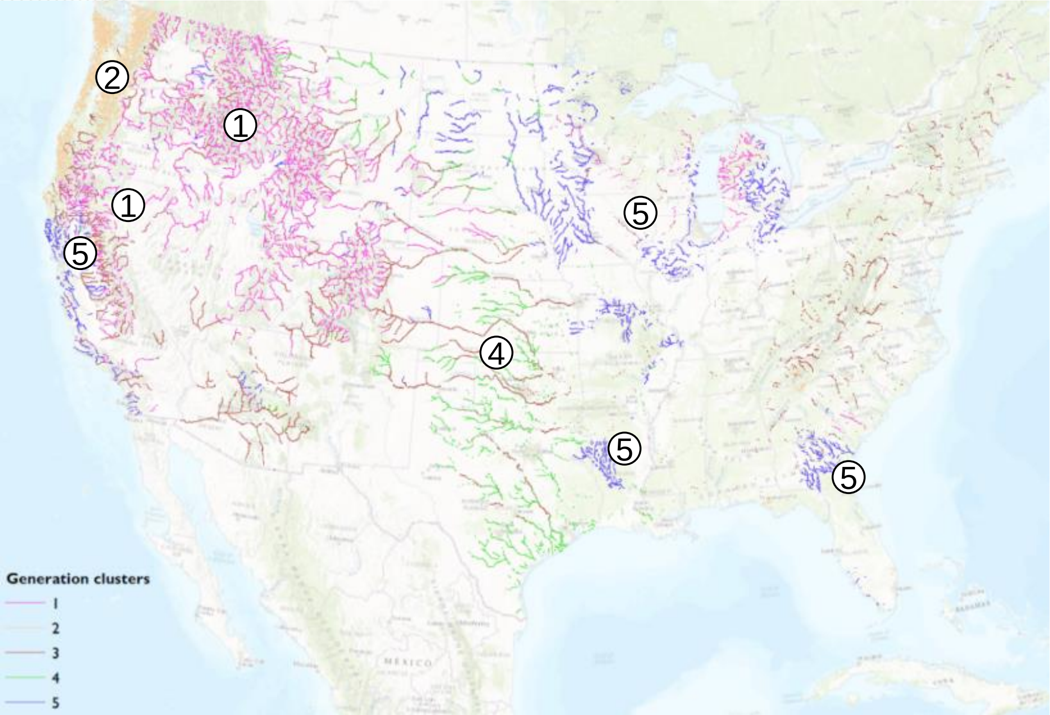
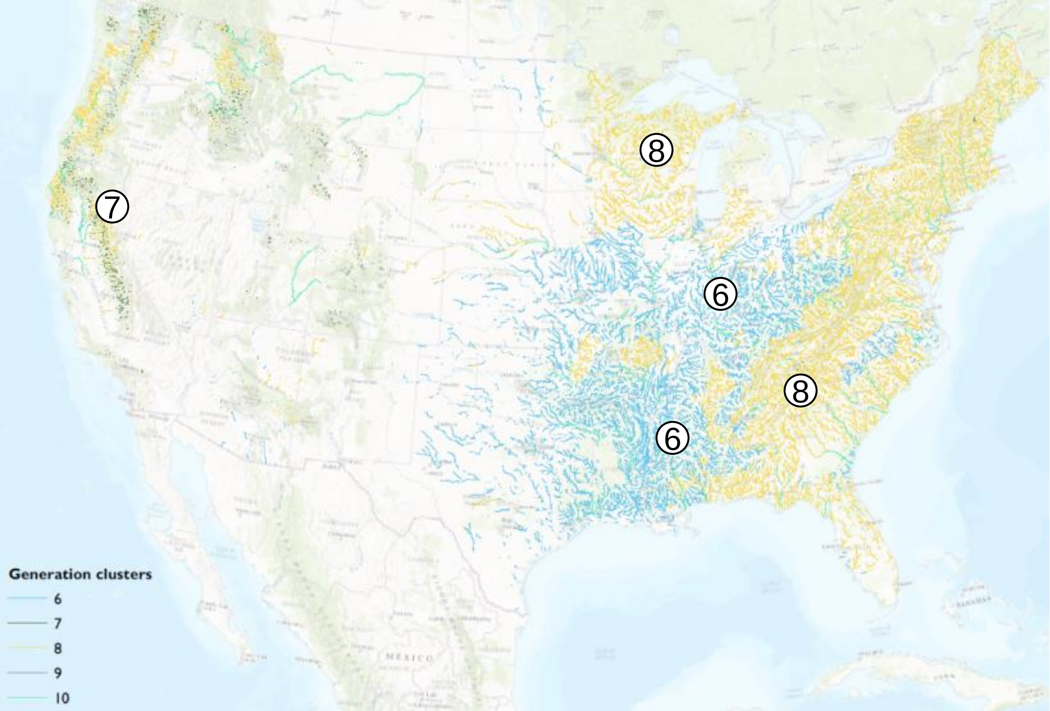
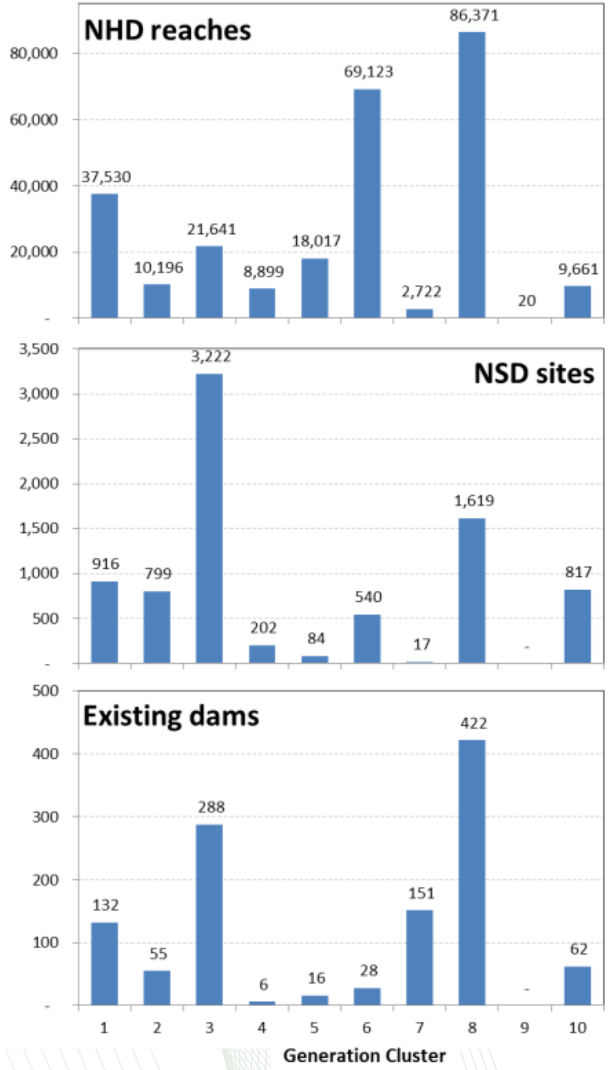
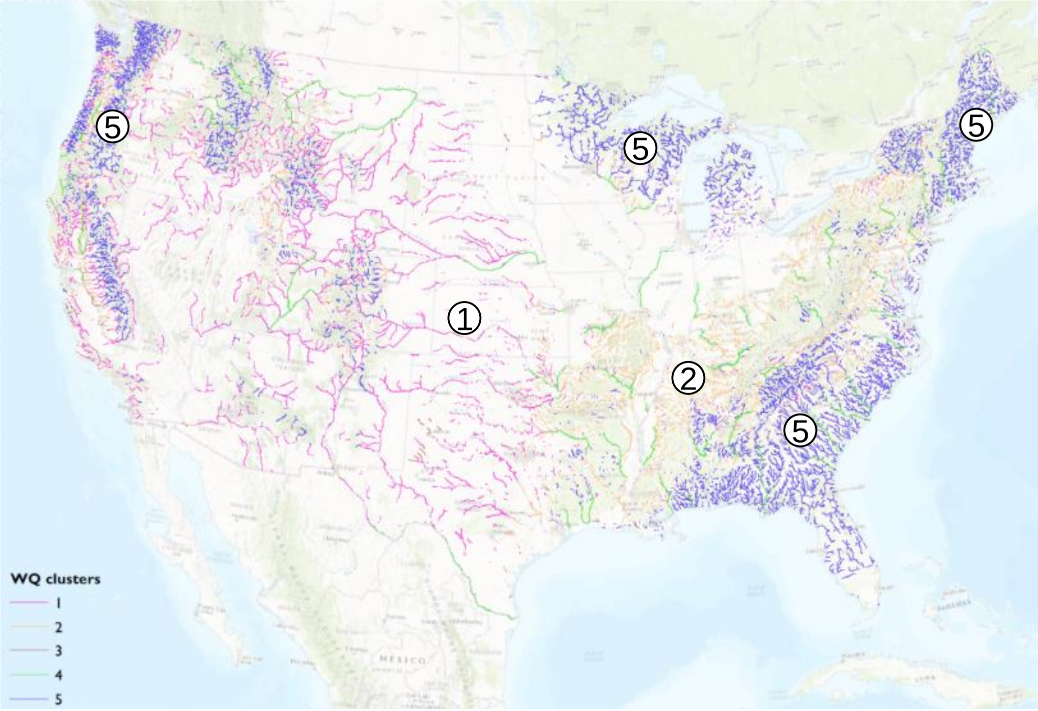
Generation

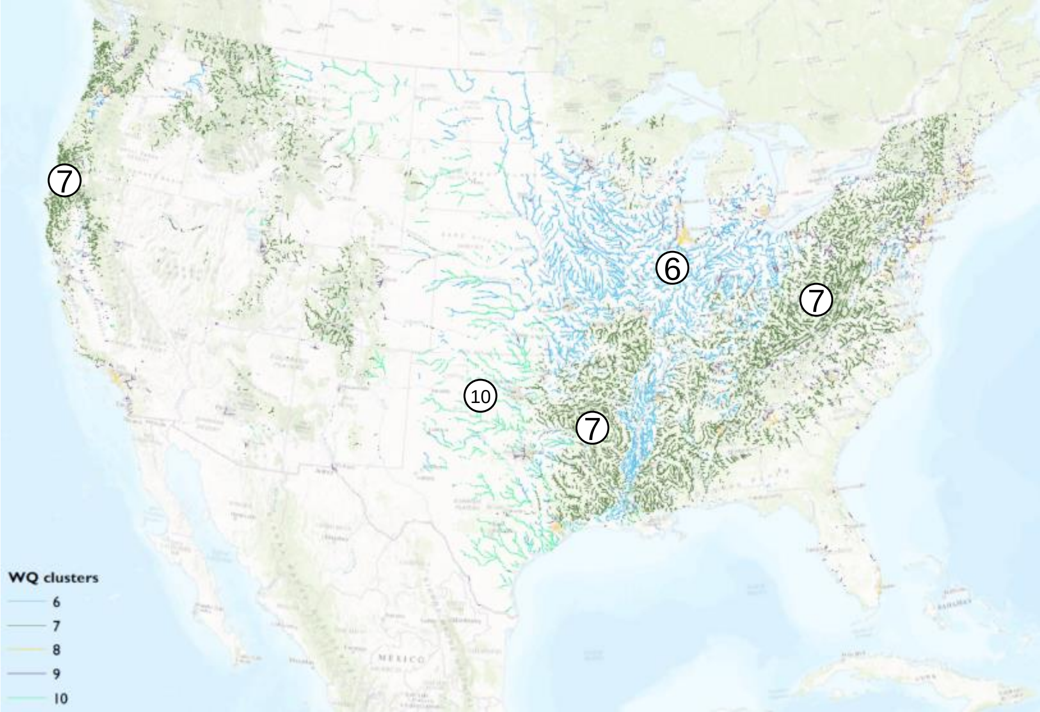




#	# Reaches	Defining characteristics	Locale
1	37,500	low Q, high baseflow, high seasonal var. (snow melt)	Rockies, Sierras
2	10,000	med Q, steep grade, high baseflow, low seasonal var.	Cascades
3	21,500	med Q, high velocity,	National
4	9,000	med Q, low grade, low baseflow,	Great plains, Texas
5	18,000	low Q, low grade, low baseflow, low velocity, high seasonal var.	National, valleys and plains
6	69,000	low Q, low grade, low baseflow, low velocity,	Mississippi Valley, Midwest and mid-south
7	2,700	low Q, steep grade, high baseflow,	Rockies, Sierras, Cascades
8	86,500	low Q, low velocity,	Great Lakes, Appalachians, Atlantic coast, west coast foothills
9	20	med Q, very steep grade(?), high velocity,	--
10	9,500	high Q, low grade,	National

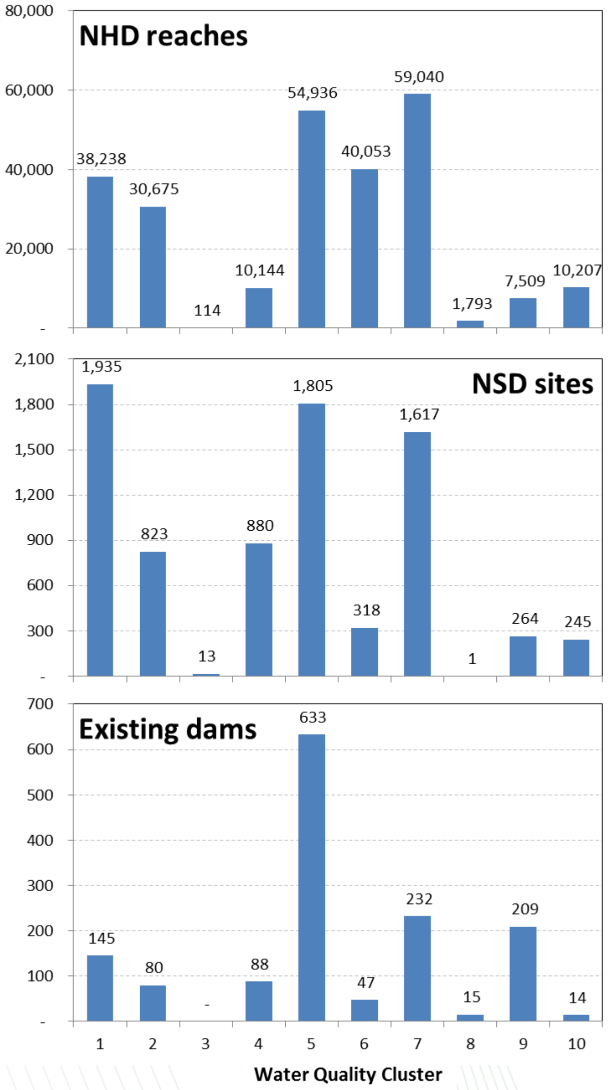






Water Quality

#	# Reaches	Defining characteristics	Locale
1	38,000	Unforested, low agric., low erodibility	Plains
2	31,000	Agricultural, high erodibility	Mississippi and Ohio R valleys
3	100	Agricultural, N runoff	--
4	10,000	Large rivers,	National
5	55,000	Forested, low erodibility	National
6	40,000	Agricultural, high erodibility, N runoff	Midwest, Ohio and Miss R
7	59,000	Forested, low ag, moderate erodibility	National
8	1,800	Small streams, urban, impervious surfaces	National
9	7,500	Suburban, impervious	
10	10,000	Agricultural, unforested, N runoff	Great plains



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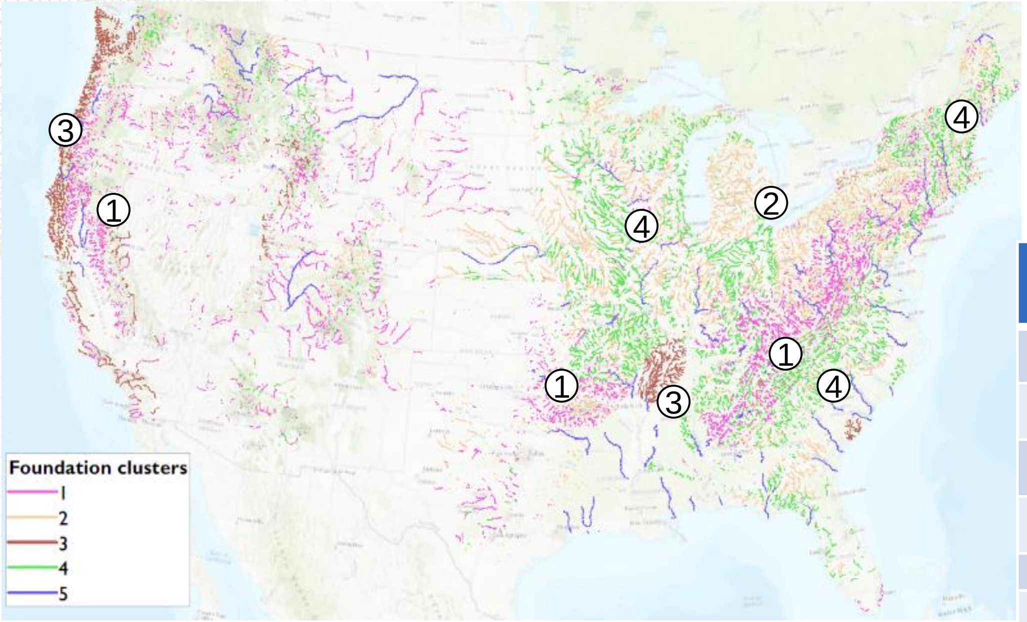
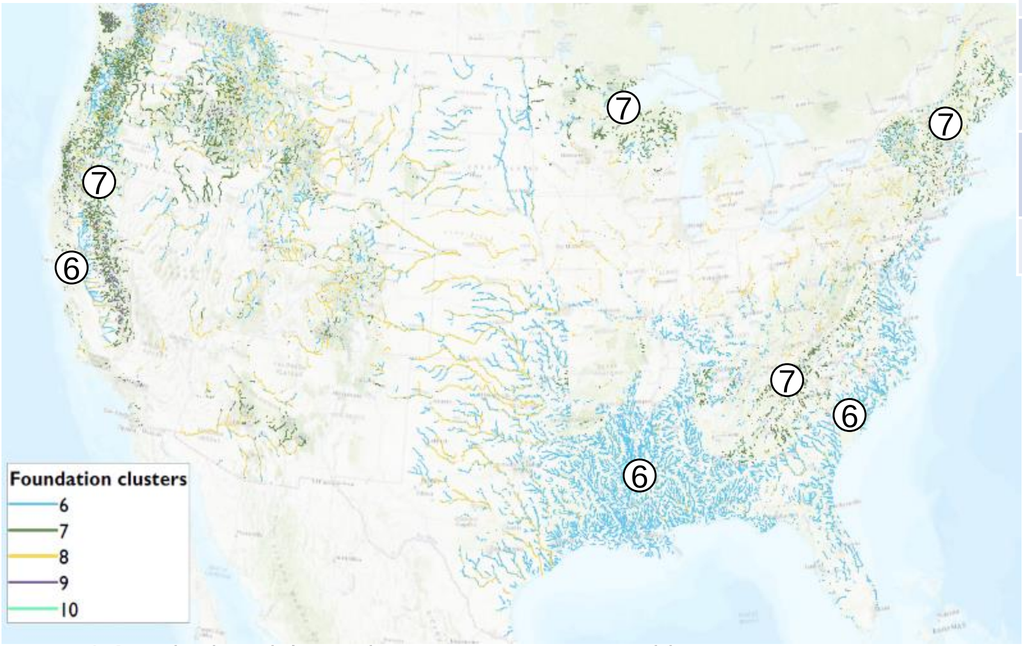
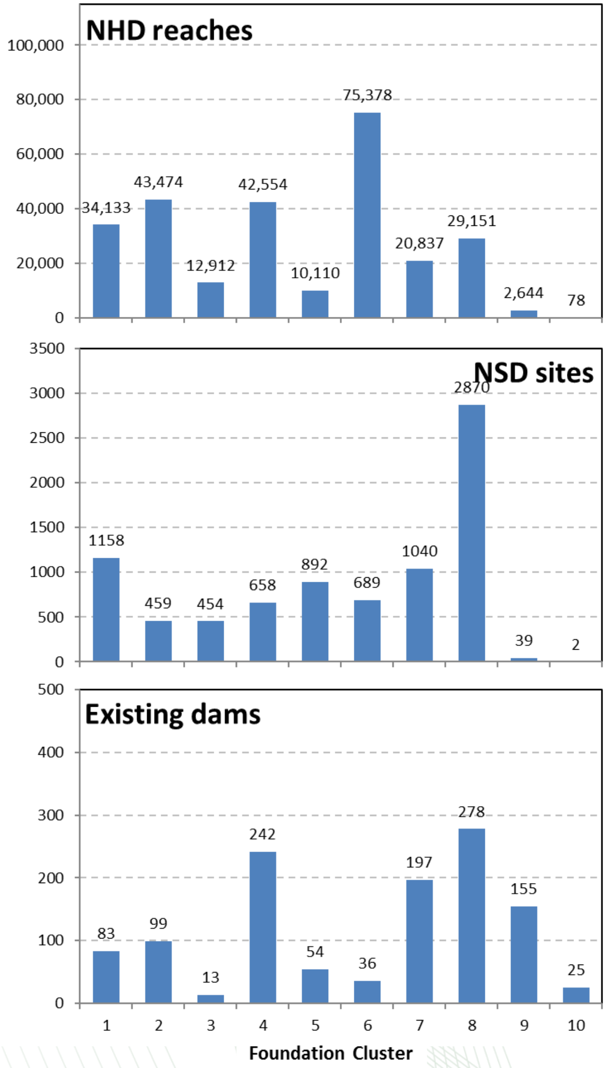




Foundation

#	# Reaches	Defining characteristics	Locale
1	34,133	Low flow, shallow bedrock,	Low mtn streams: foothills Appalachian, Ozark, Sierras
2	43,474	Low power, low flow, low gradient	Lowlands: Glaciated Great Lakes, Upper Mississippi
3	12,912	Highest earthquake hazard, high erodibility	Pacific coast, New Madrid fault, S. Carolina coast
4	42,554	Low power, low erodibility, low flow, low gradient	Lowlands: Midwest, Ntheast, and Stheast
5	10,110	High flow, high power, high velocity	Large rivers: National
6	75,378	Low power, high erodibility, low flow, low gradient	Lowlands: Stheast and Gulf coasts, Central Valley Ca
7	20,837	Moderately high power, high velocity, low erodibility, shallow bedrock	Foothill streams: Pac NW, Rockies, Appalach., Maine
8	29,151	High erodibility, high flow, moderately high velocity	National
9	2,644	Low erodibility, very high power, shallow bedrock, high gradient, moderately high velocity	--
10	78	Low erodibility, high flow, very high gradient, very high velocity	--



Webinar Agenda

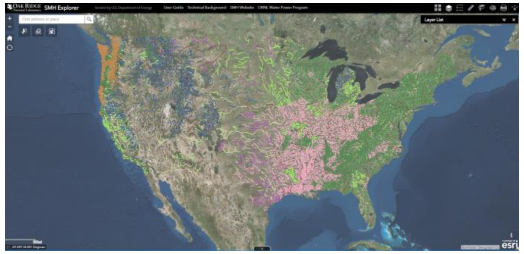
Introduction/Motivation

5 min

Site Classification

10 min

SMH Explorer



15 min

Modular Design

15 min

Q&A

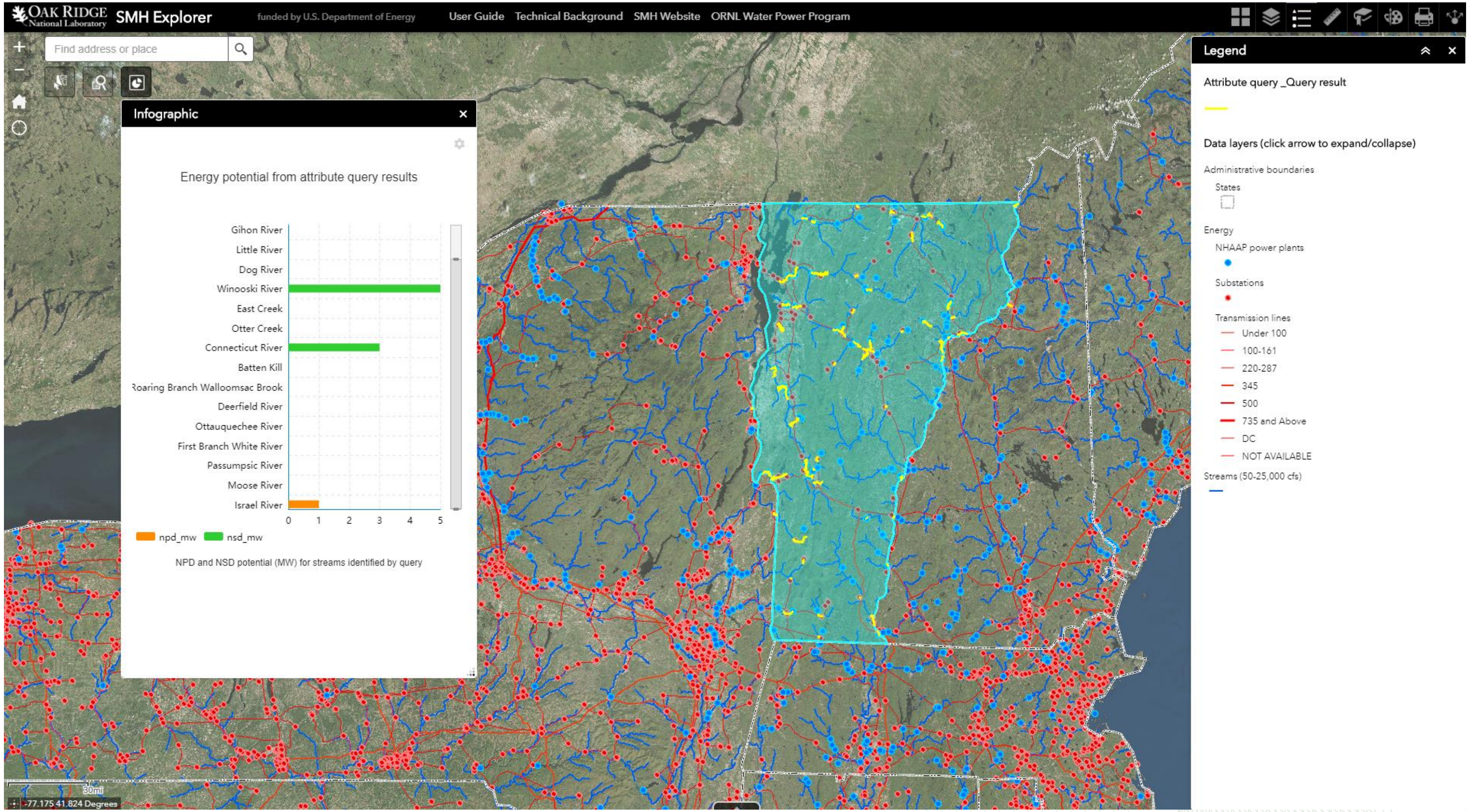
15 min

About SMH Explorer

- A **geovisual analytics platform** that empowers user-guided energy-water-environment-module data analysis and inquiries in support of the SMH project.

- The tool can be used to **establish scoping-level insights into** the type of foundation, generation, water quality, fish passage, recreation, and sediment **modules that may be required** if hydropower development is pursued on a stream-reach.

https://hydropower.ornl.gov/smh/explorer/



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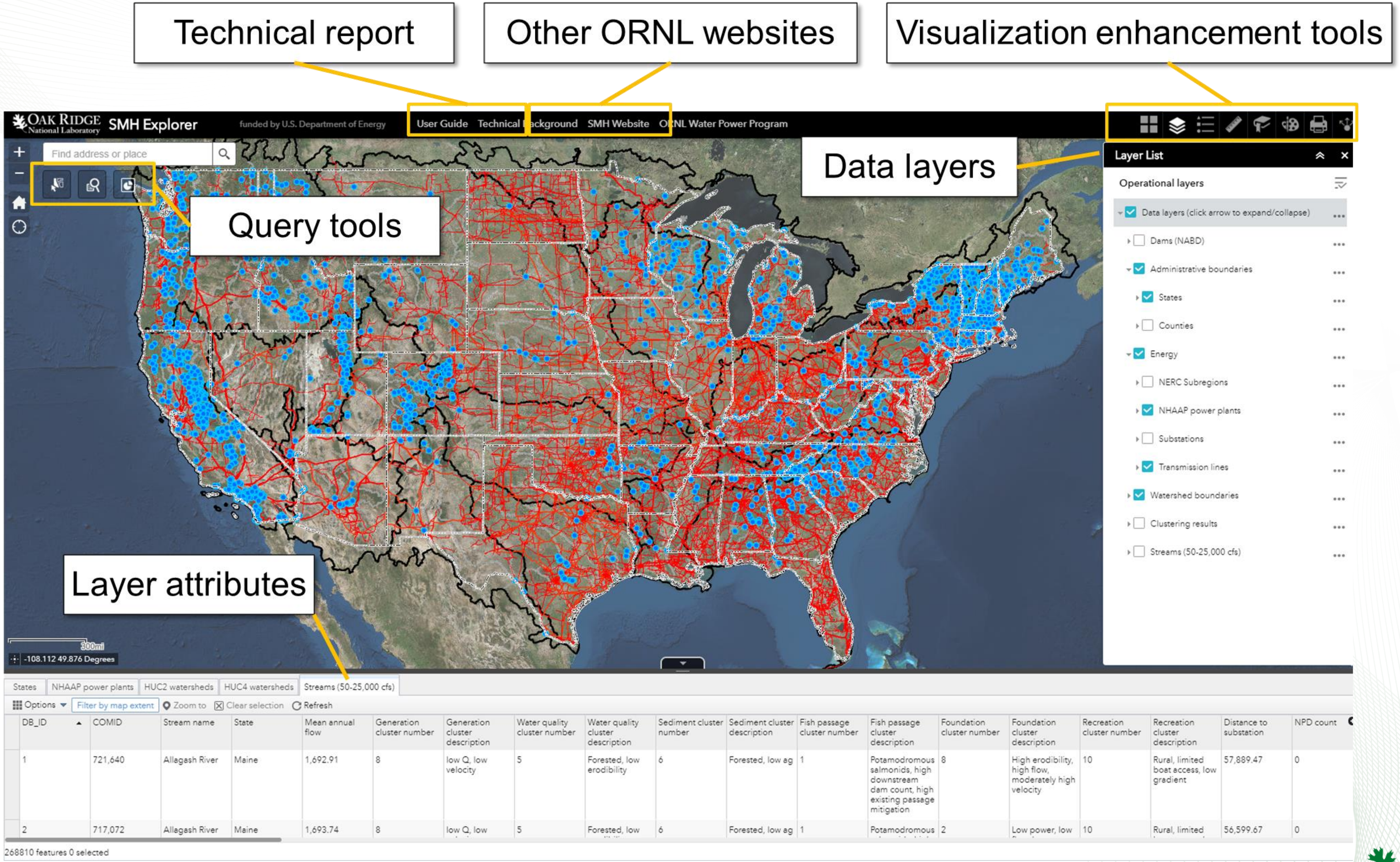
Functionality

The basic functionality of SMH Explorer falls into two categories:

- **Data layers** and **user queries**.
  - **Data layers** provide geospatial information about different energy and landscape characteristics.
    - There are currently **18 data layers** in SMH Explorer (including clustering results)
  - The **user queries** function allows users to input specific search criteria, visualize results, and download data summaries.
    - There are currently **>80 attributes** that users can query in SMH Explorer (including clustering results)

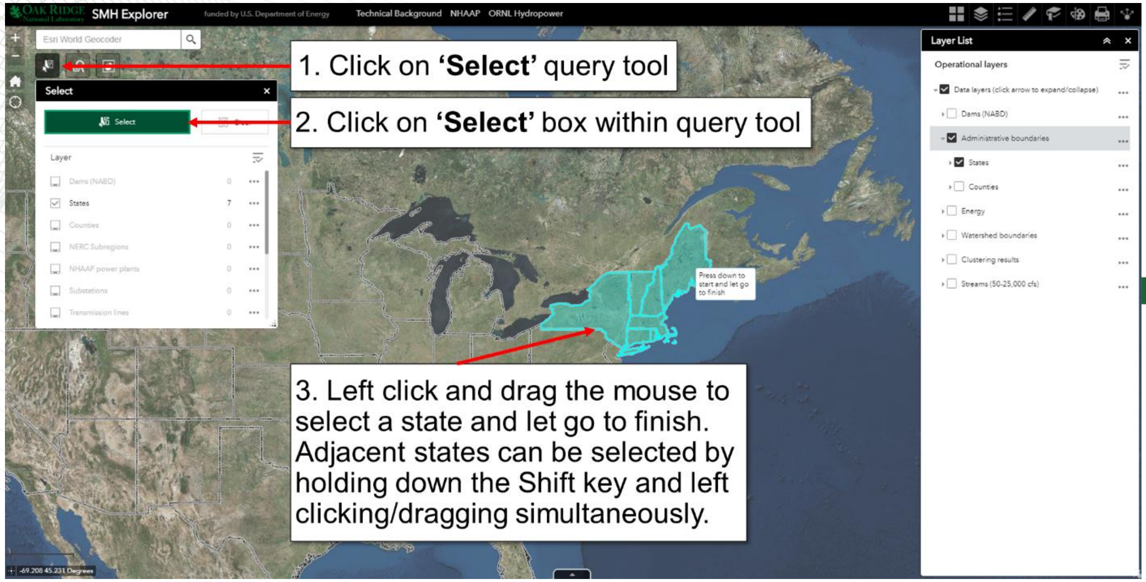
User interface

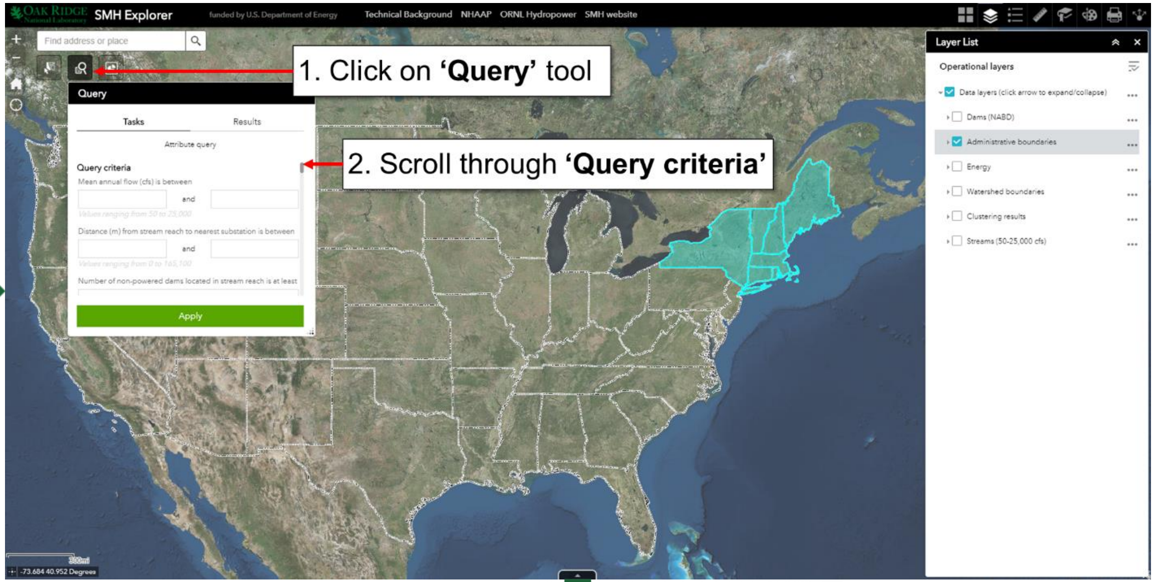


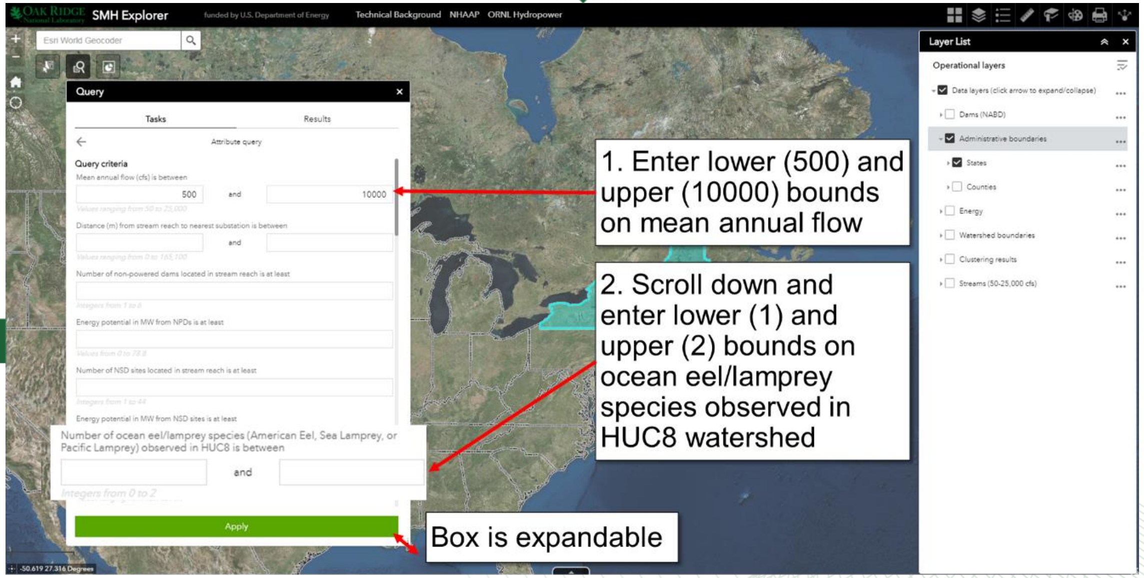
Use Case 1: Module developer determining application space

- A module developer might want to know how much **demand** there is **for a particular module design**.
- This information could be useful for **pre-development decision-making and post-development marketing**.
- For example, how many sites or how big of an area might benefit from a **fish passage module** that passes a **particular species** group?
- In this example, the search focuses on the **Northeast**, where fish passage structures are commonly located at existing hydropower facilities.
- It also is limited to **ocean eel and lamprey**, species of concern with specific passage requirements.

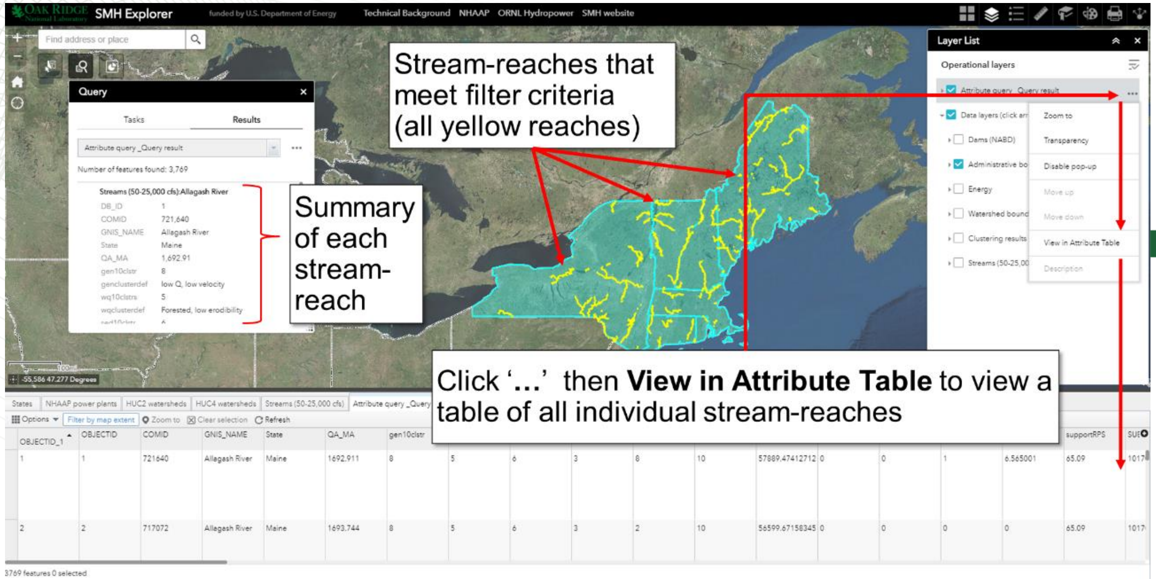
Use Case 1: Module developer determining application space

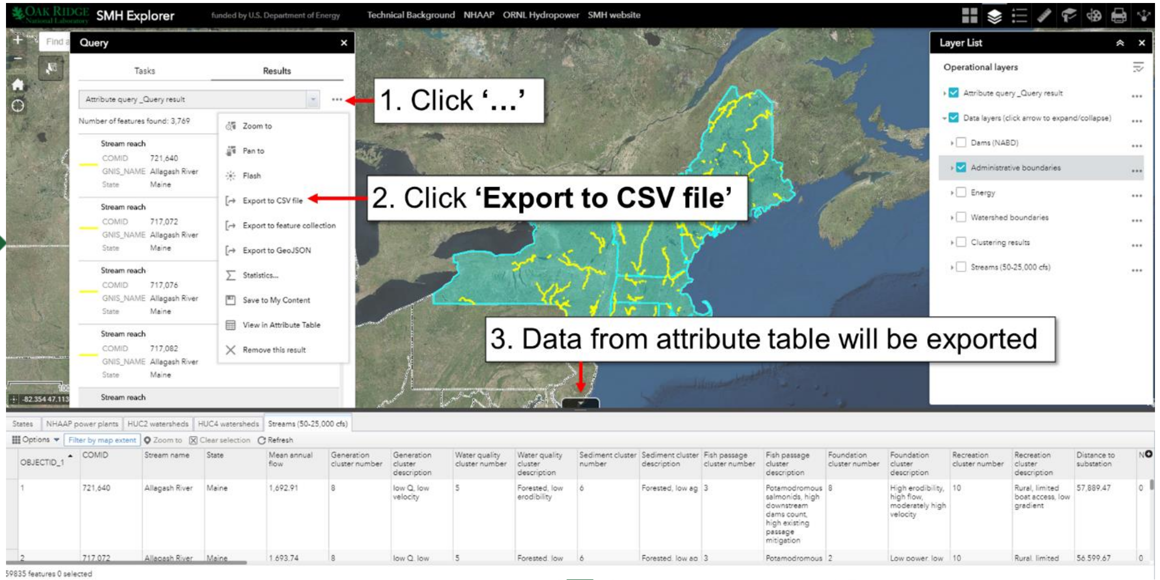


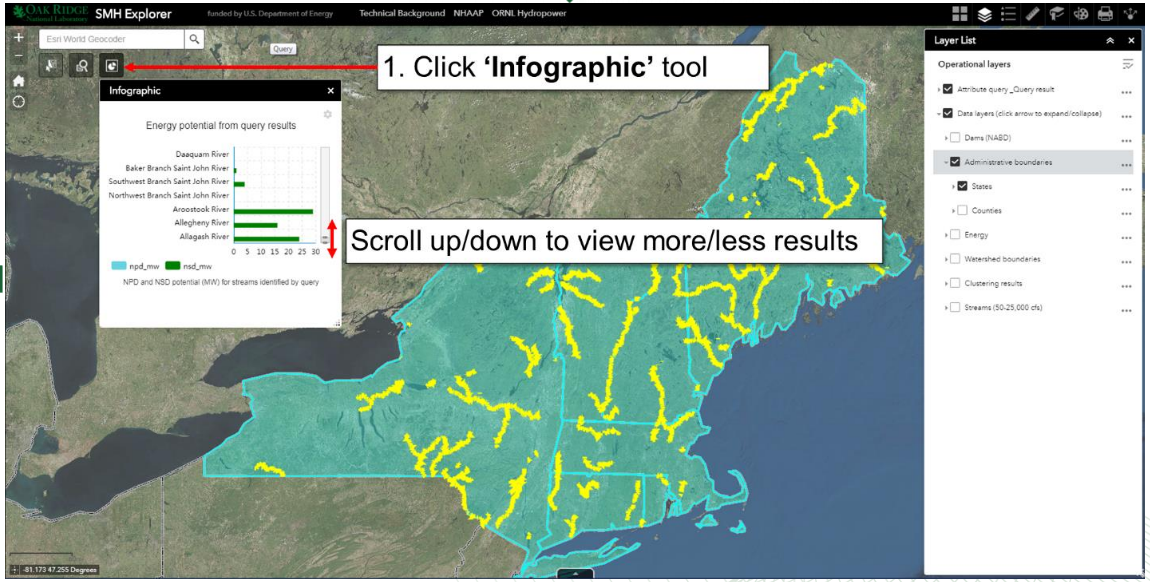




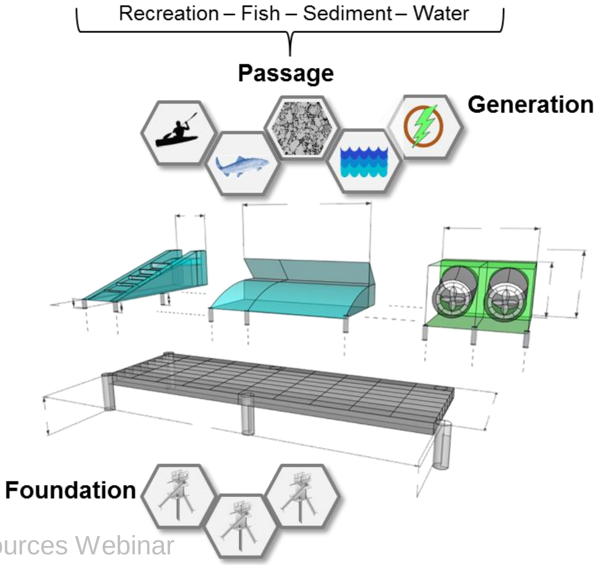
Use Case 1 continued







Potential application space for module



Use Case 2: Project developer assessing module need at site and identifying similar sites

- Suppose a **project developer** has a site they would like to consider for hydropower development and wants to know **what modules may be needed**, based on the **environmental characteristics** of the stream-reach.
- In this example, we pick an **NSD site** in the Pacific Northwest, one of the only regions in which NSD has been pursued in the past few decades and a location with significant **NSD potential** that was deployed within the **Hydropower Vision** capacity expansion model.

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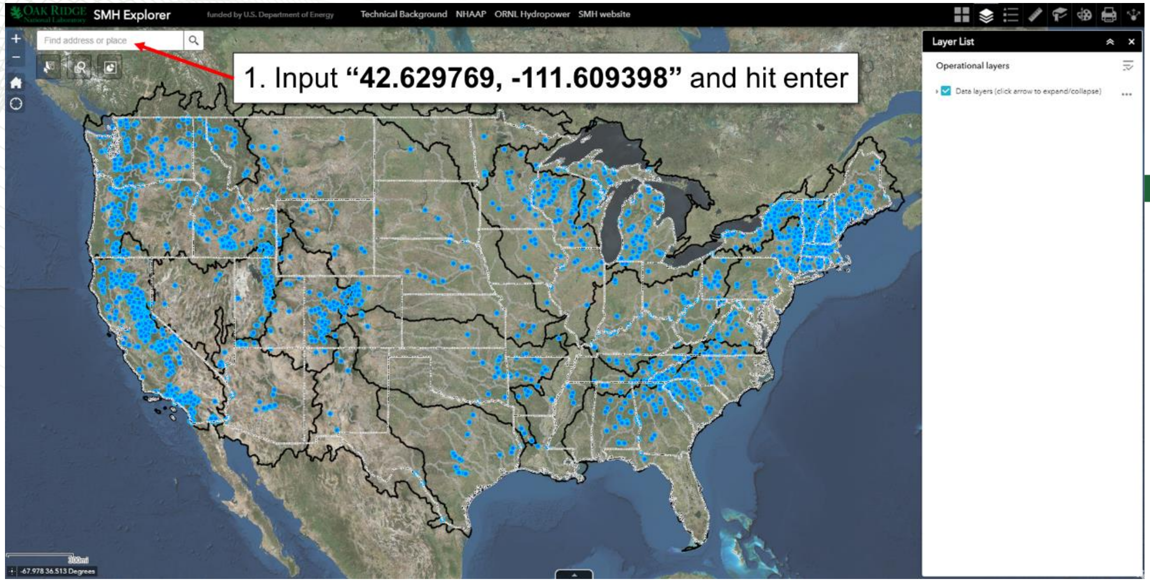
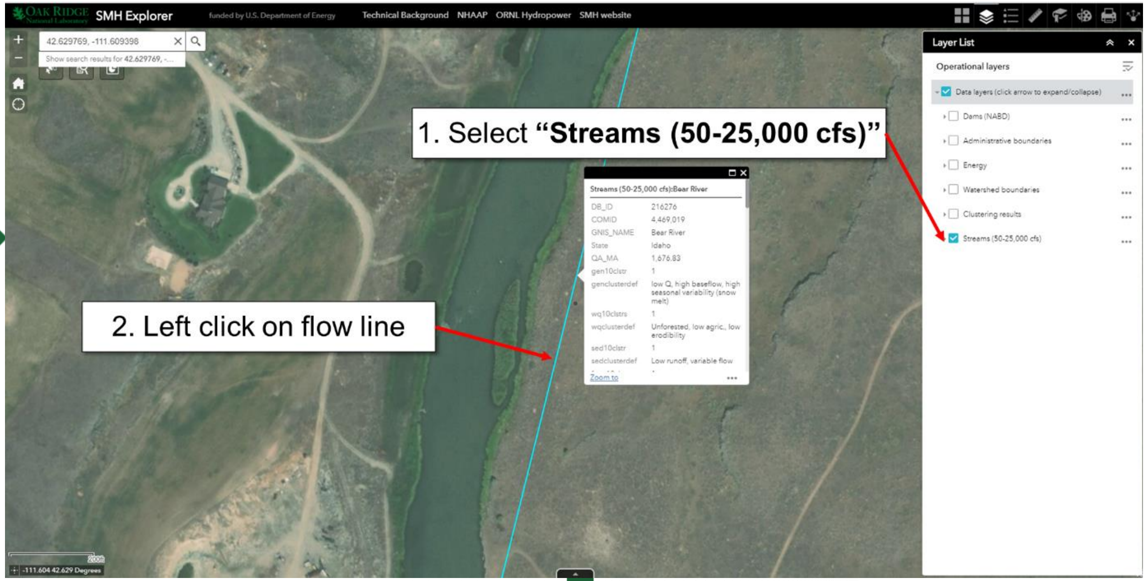
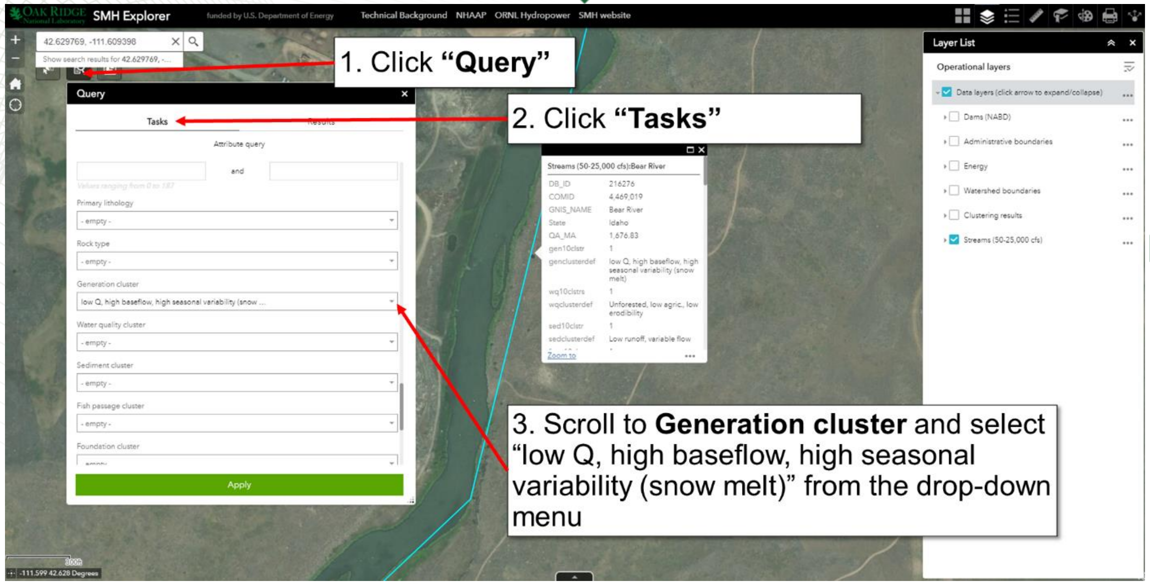
Use Case 2: Project developer assessing module need at site and identifying similar sites

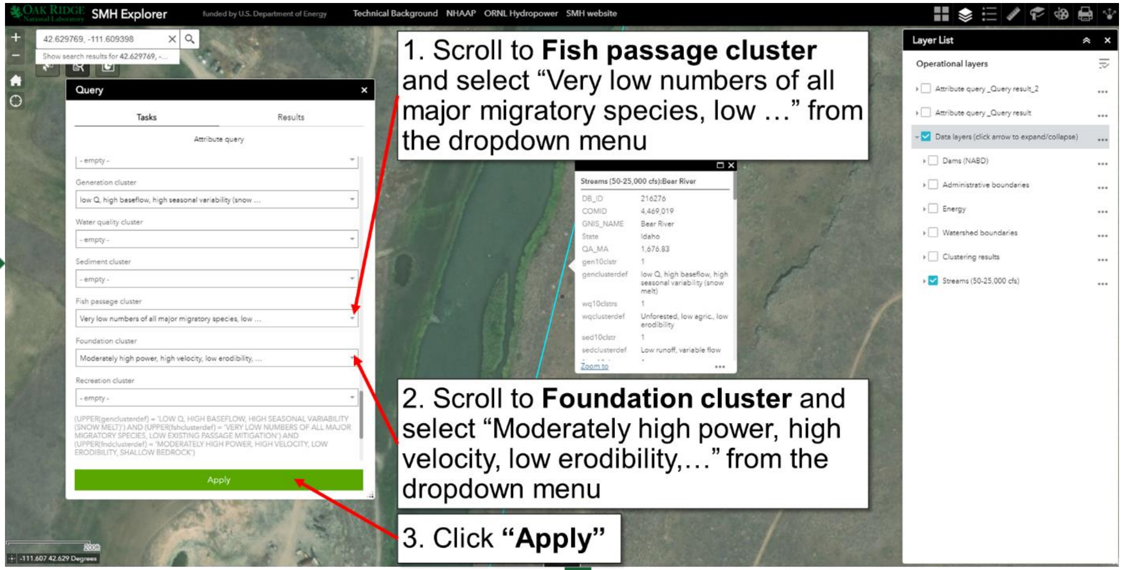


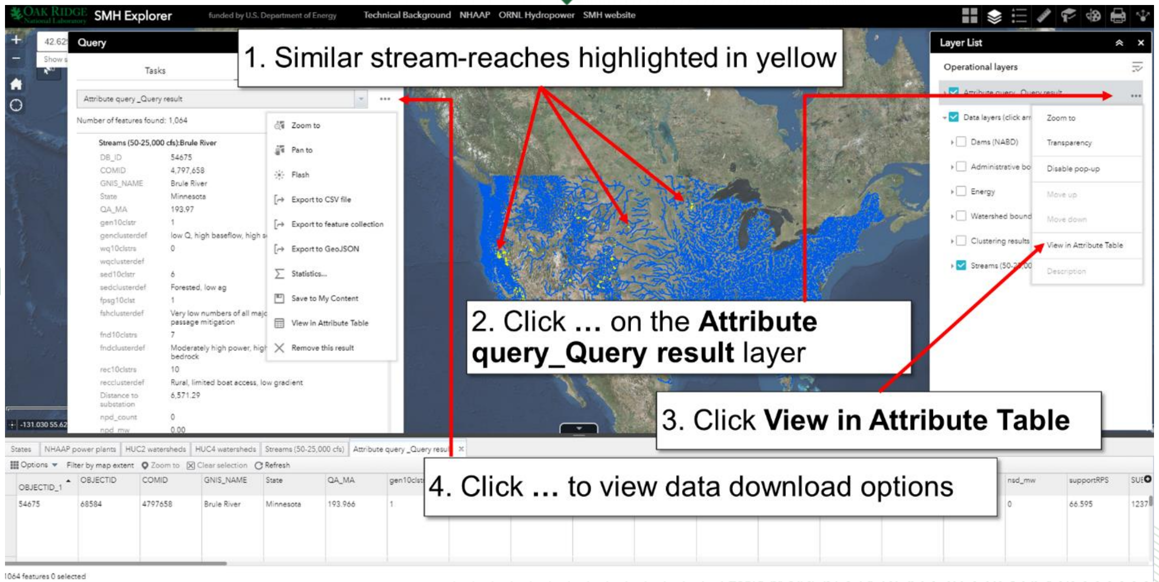


Module	Cluster number	Number of reaches	Defining characteristics	Locale
Generation	1	37,500	Low Q, high baseflow, high seasonal variability (snow melt)	Rockies, Sierras
Water quality	1	38,238	Unforested, low agricultural, low erodibility	Plains
Sediment	1	34,841	Low runoff, variable flow	Mountain West and Plains
Fish passage	7	94,507	Very low numbers of all major migratory species, low existing passage mitigation	Scattered nationally
Foundation	7	20,837	Moderately high power, high velocity, low erodibility, shallow bedrock	Foothill streams: Pacific NW, Rockies, Appalachians, Maine
Recreation	10	159,406	Rural, limited boat access, low gradient	Ohio and Mississippi River valleys, eastern Great Lakes, Great Plains

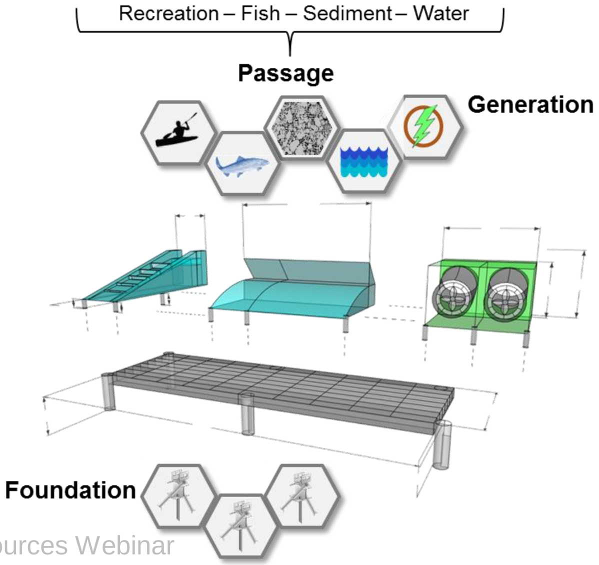
Use Case 2 continued







Potential for common design requirements and standard plant design



Webinar Agenda

Introduction/Motivation

5 min

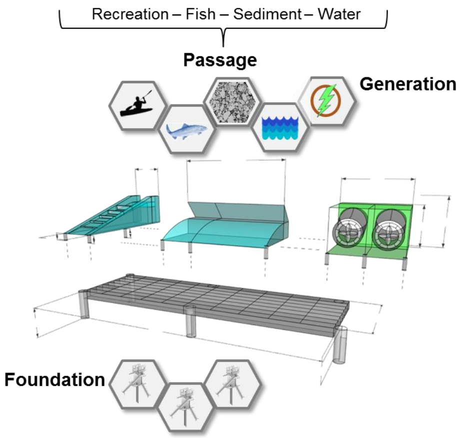
Site Classification

10 min

SMH Explorer

15 min

Modular Design



15 min

Q&A

15 min

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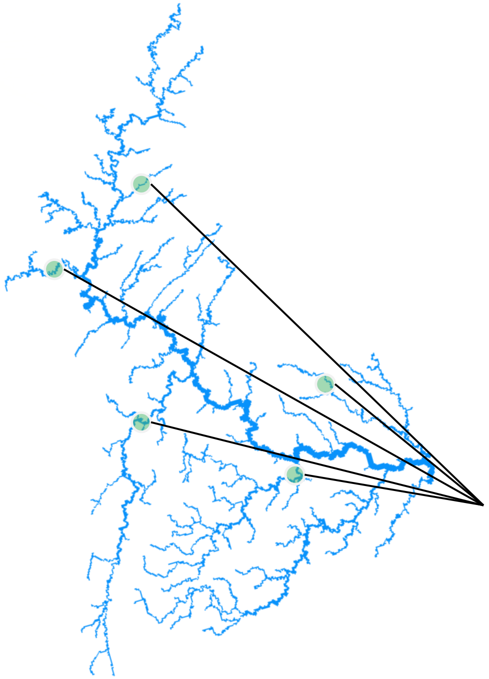
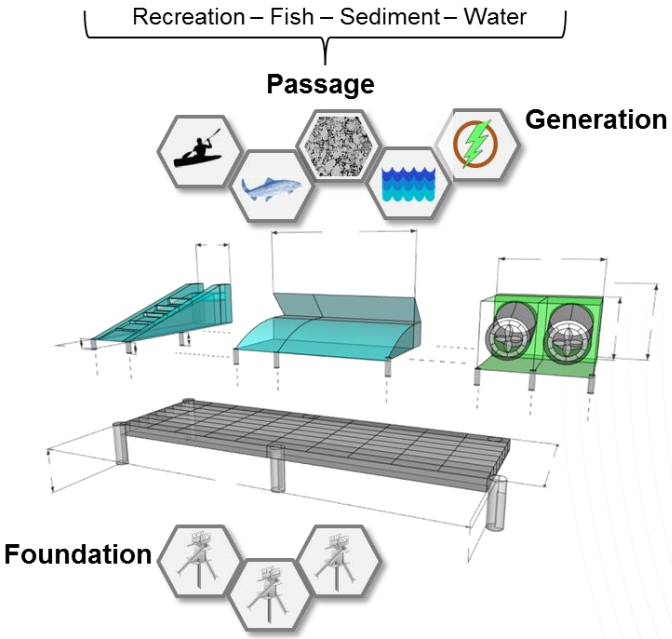
Exemplary Design Envelope Specification (EDES)

For a cluster of sites,



how do we establish a suitable and scalable design envelope for modules and modular facilities?



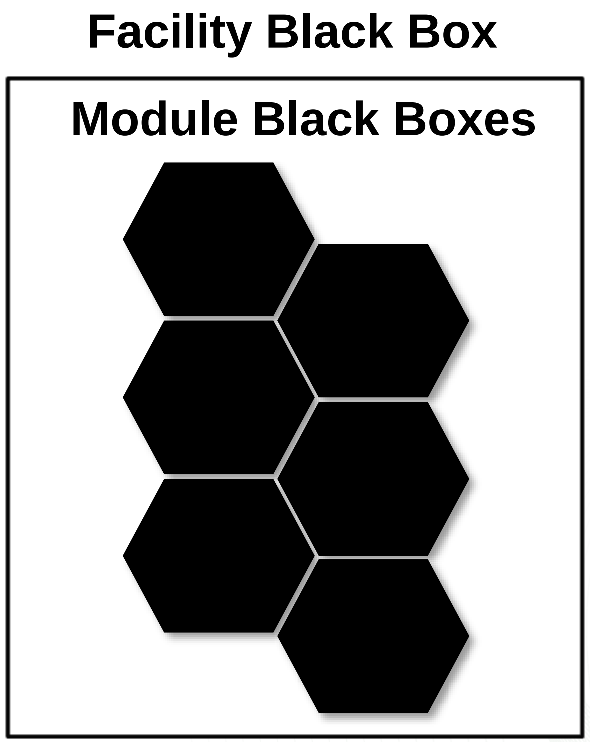
Exemplary Design Envelope Specification (EDES)

A framework for technology-neutral SMH conceptual design

EDES goal

Develop a hydropower facility comprised of modules that:

- can be independently ordered, configured, or delivered
- can be independently developed with compatible module-to-module interfaces
- can be independently deployed across a set of distributed sites
- can be swapped in and out without compromising facility performance
- can be transported individually to a site and combined to construct a whole hydropower facility



Exemplary Design Envelope Specification (EDES)

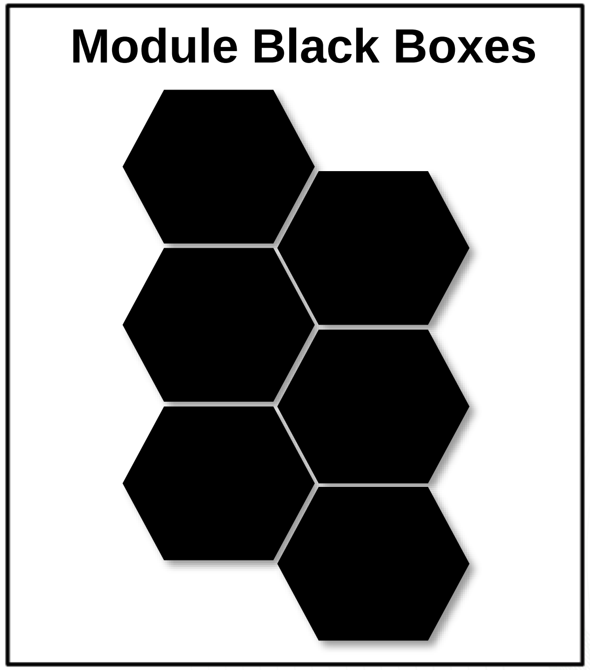
A framework for technology-neutral SMH conceptual design

New design continuum

ORNL work to date along new design continuum

For more details and full design envelope specification for each module see:
https://hydropower.ornl.gov/smh/docs/ORNL-SMH-Exemplary-Design-Envelope-Specification.pdf

Facility Black Box



Exemplary Design Envelope Specification (EDES)

A framework for technology-neutral SMH conceptual design

Inputs
- variables that govern stream and module behavior

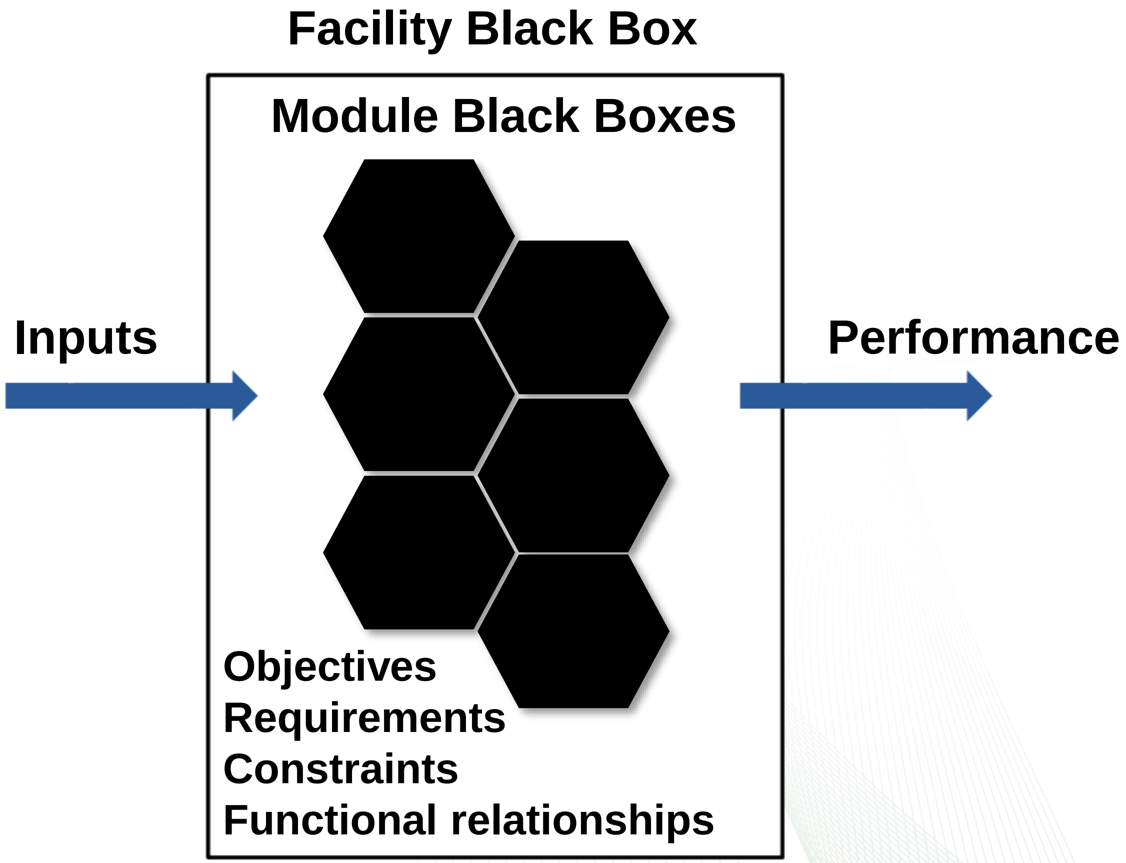
Objectives
- primary function to be achieved as a result of deploying and operating a module

Requirements
- a behavior or function that must be performed by a module for successful operation

Constraints
- a limitation on the value of a design parameter or an operation

Performance
- a set of quantifiable indices or metrics that enable the evaluation of how well an objective is met

Functional relationships
- parametrized linkage of inputs to objectives and performance



SMH facility objectives (i.e., system objectives)

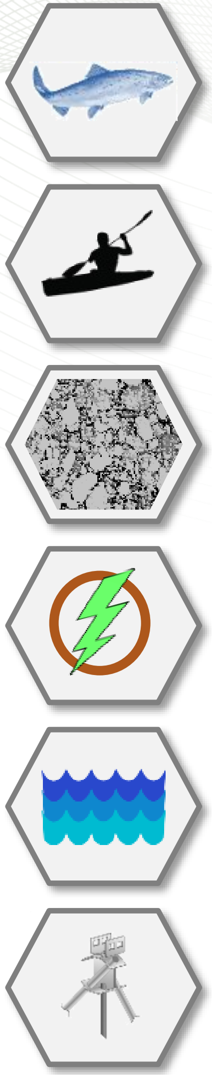
A framework for technology-neutral SMH conceptual design

Start by defining objectives of SMH facilities:

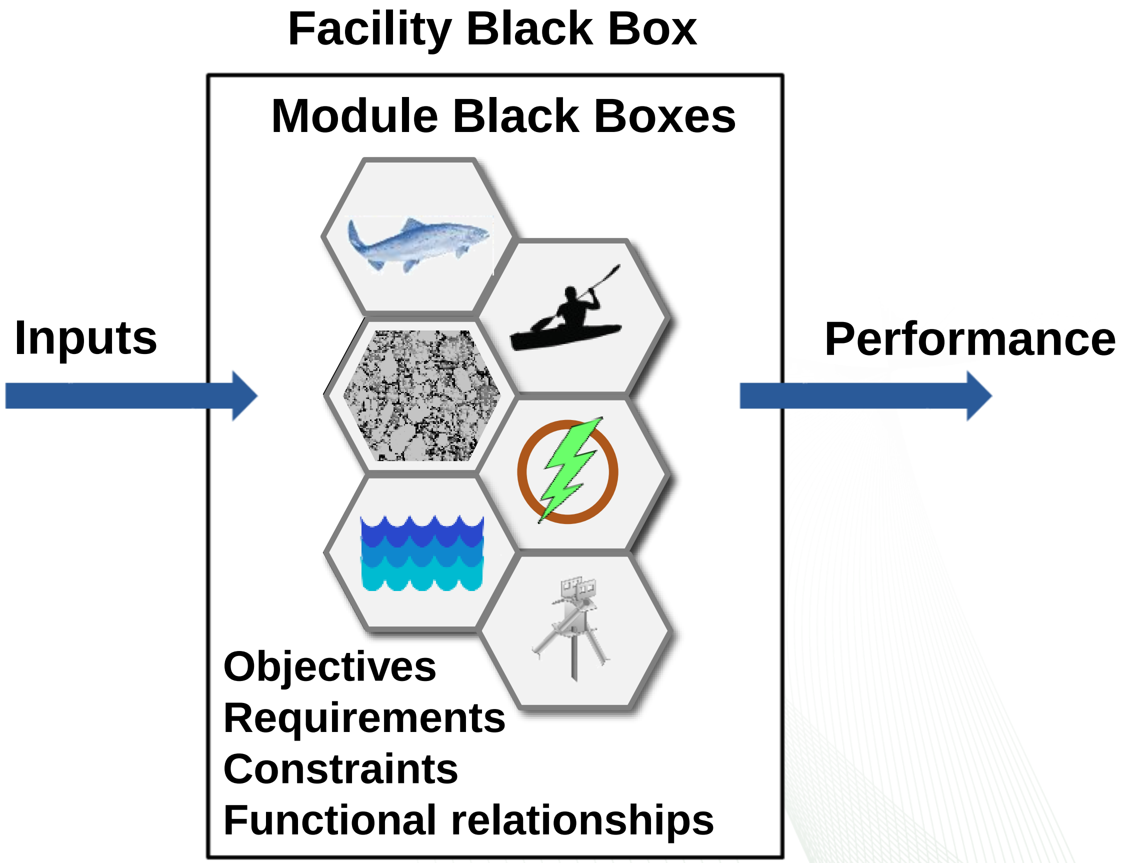
- predictable and regular production of electricity
- cost competitive with other small renewables
- minimize alteration of the inflow hydrograph (i.e., run-of-river operation)
- minimal impoundment (i.e., low degree of regulation)
- minimize fluctuations of water surface elevation
- environmental technology integral to the facility design
- safe and timely passage of fish, sediment, and recreational craft
- non-degradation of water quality
- minimize disruption to the aesthetics of the natural stream and streamscape
- deliver additional environmental or natural resource co-benefits beyond generation (e.g. water quality enhancement, invasive species control, hydrologic restoration, recreation opportunities, etc.)

Facility Black Box

Module objectives (i.e., sub-system objectives)



- allow the unimpeded and safe passage (upstream and downstream) of fish through a SMH facility
- allow the passage of small recreational craft consistently and safely through a SMH facility
- allow the transport of incoming sediment through a SMH facility
- generate hydroelectric power from flowing water under pressure
- convey non-generating water over or through the SMH facility
- anchor passage and generation modules to the streambed and banks



Fish passage module design envelope specification

allow the unimpeded and safe passage (upstream and downstream) of fish through a SMH facility

Inputs
- Fish species and physical/biological characteristics
- Flow variables
- Module geometric variables
- Geomorphologic variables

Requirements
- Attract fish to the module inlet
- Allow fish to cross the SMH facility
- Allow fish to exit safely into the river
- Integrate structurally into the foundation module

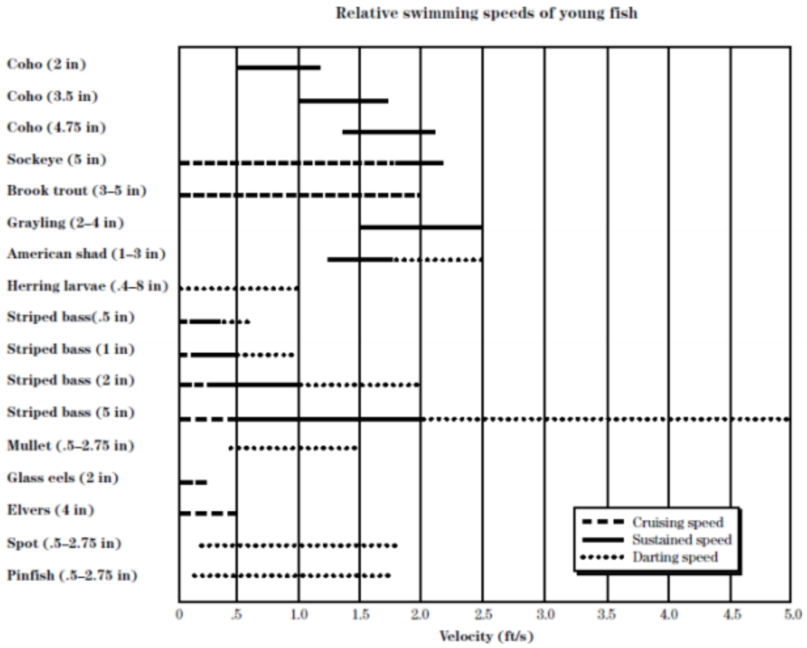
Constraints
- Module elements cannot create barriers or drops higher than the jumping ability of encountered fish species
- The module must create favorable flow conditions at its inlet for fish to enter
- Slope, velocity, depth, length, flow patterns, and turbulence must be acceptable to species being passed
- Module components cannot exceed in size the size of available transport vehicles or vessels

Fish passage module design envelope specification

allow the unimpeded and safe passage (upstream and downstream) of fish through a SMH facility

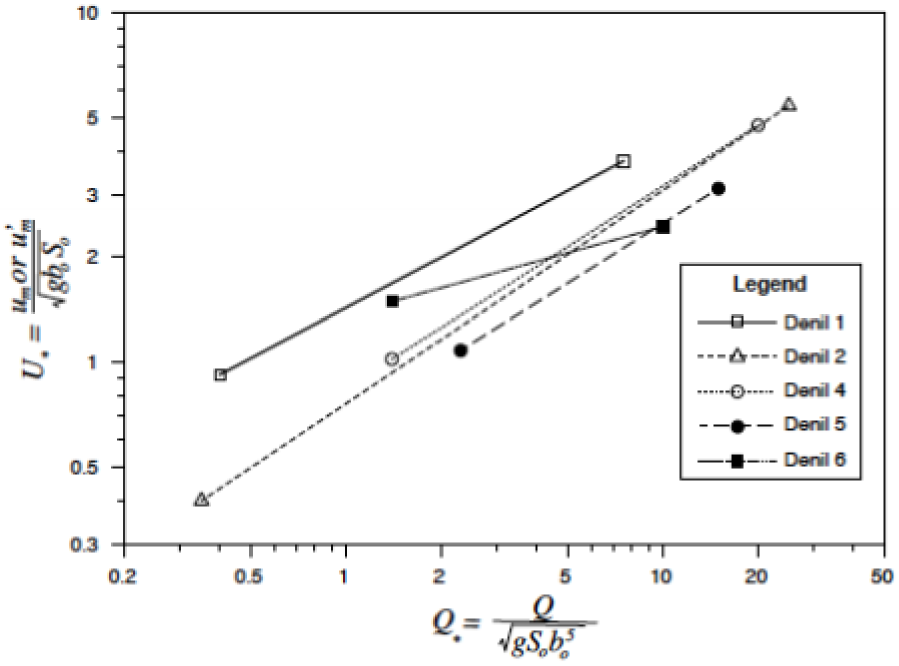
Functional relationships (examples from EDES for conventional design)

Swimming velocity as function of fish species



(NRCS 2007)

Passage flow velocity as function of design discharge and geometry



(Katopodis 1992)

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Fish passage module design envelope specification

allow the unimpeded and safe passage (upstream and downstream) of fish through a SMH facility

Using the EDES	**Identify set of site inputs**	**Develop concept that meets objectives, requirements, and constraints**	**Identify functional relationships**	**Use functional relationships to estimate performance**	**Commence preliminary design iteration**
Fish passage module example	Species of interest and flow data	Modular fish ladder	Sizing and hydraulics technical guidance	Hydraulics, design flow, attraction flow, footprint, cost, etc.	

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Generation module design envelope specification

generate hydroelectric power from flowing water under pressure

Inputs

- River discharge (flow duration curve, mean annual flow, minimum environmental flow requirements)
- Range of heads (headwater and tailwater high and low elevations, net head, tailwater submergence)
- River geometry (wetted perimeter, width, bottom width)
- Electrical frequency of customer (AC frequency of the customer to which generation module must be synchronized)
- Desired power quality (total harmonic distortion, power factor
- Voltage (output voltage desired at the grid or customer connection)

Requirements

- Take in flow (with provisions for shutoff and trash racks)
- Direct the flow to the hydraulic turbine chamber
- Convert hydraulic power into mechanical power into electrical power
- Prepare electrical power for distribution to the customer
- Release flow
- Integrate structurally into the foundation module

Constraints

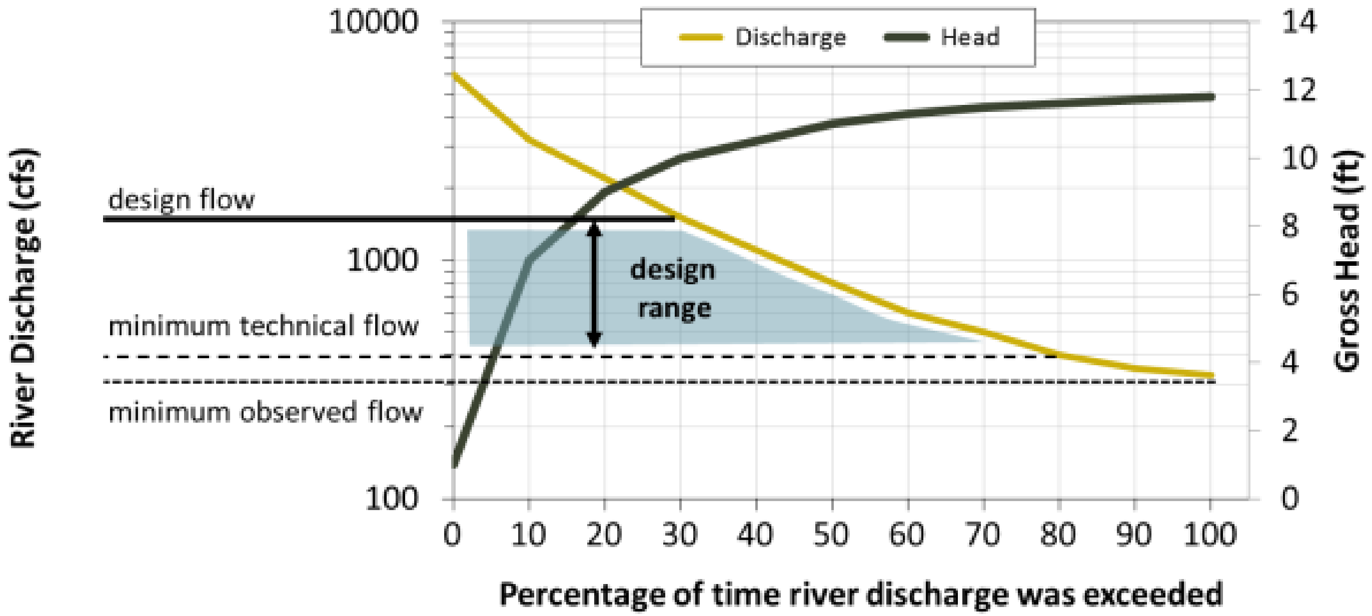
- Must be run-of-river and operate within natural variations of head and flow
- Must maintain safe operation of equipment and systems within the generation module during all operational scenarios (normal operations, flood, drought, special hydraulic operations, emergency shutdown, startup, and ramping up and down)
- Must accommodate heads of less than 30 ft and flows less than 4,000 cfs
- Must use biodegradable oil and lubricants or water-lubricated bearings
- Cannot kill or injure fish
- Must conform with all relevant standards and codes for hydropower generators

Generation module design envelope specification

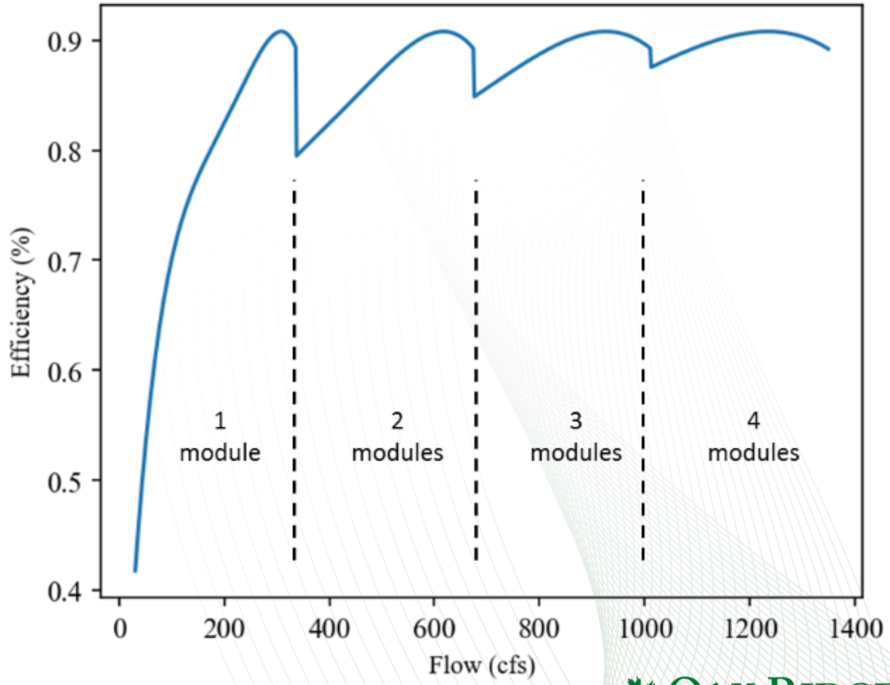
generate hydroelectric power from flowing water under pressure

Functional relationships (examples from EDES for conventional design)

Generation module design flow as function of river discharge



Generation module efficiency as function of discharge



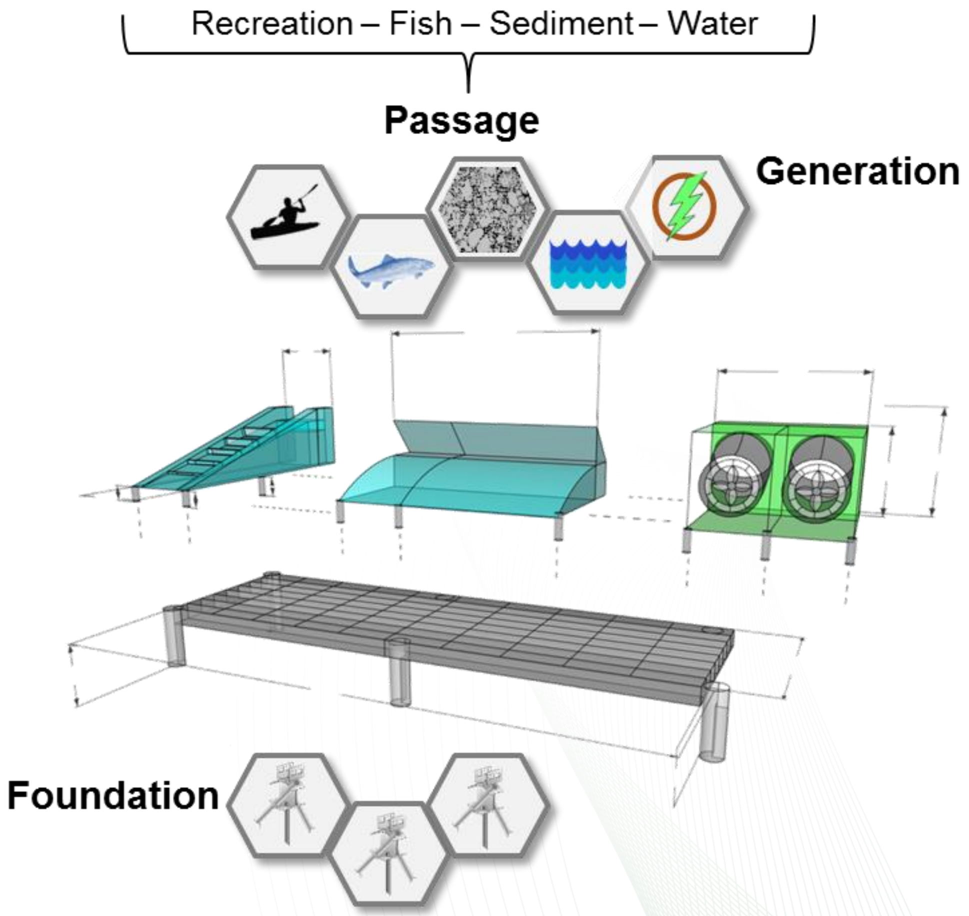
Generation module design envelope specification

generate hydroelectric power from flowing water under pressure

Using the EDES	**Identify set of site inputs**	**Develop concept that meets objectives, requirements, and constraints**	**Identify functional relationships**	**Use functional relationships to estimate performance**	**Commence preliminary design iteration**
Generation module example	Flow and head/stage data	Generation module with intake, trash rack, runner, generator, shutoff, and outlet	Efficiency curves, hill charts, specific speed, etc.	Installed capacity, power duration curve, footprint, cost, etc.	

EDES Desired Innovation

- Developing modules that require **few changes to major design features** when deployed across different sites
- Modules with **multi-functionality** (e.g., combined fish and recreation passage)
- **Fully submersible** modules and plant design
- Require **limited or no dewatering** during construction and installation
- Foundation modules that **minimize civil works**
- Modules or major module elements delivered as a **complete unit** skid-mounted to the project location
- **Passage modules integral** to plant design
- **Smart modules** with integrated control and monitoring sensor packages



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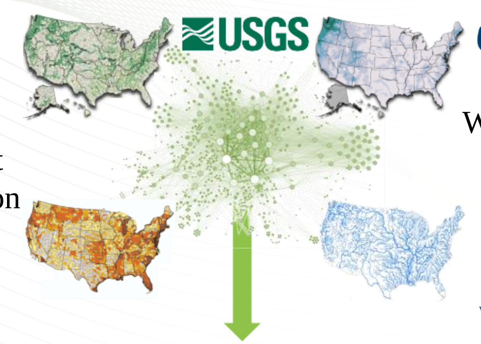
Standard Modular Hydropower Concept Recap

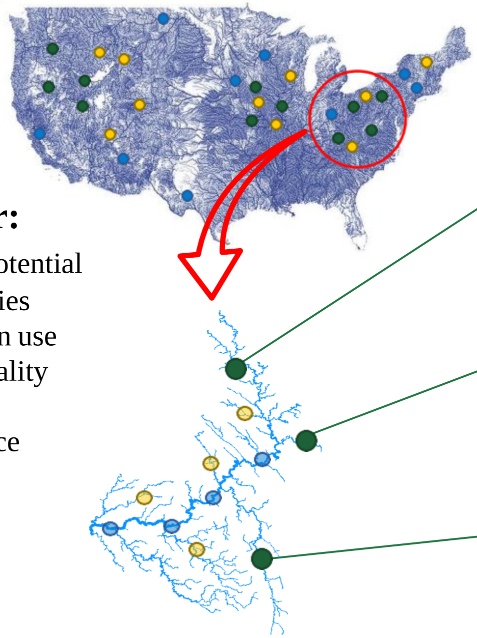
Data aggregation and site classification

Fish
Sediment
Recreation



Water Quality
Energy
Foundation

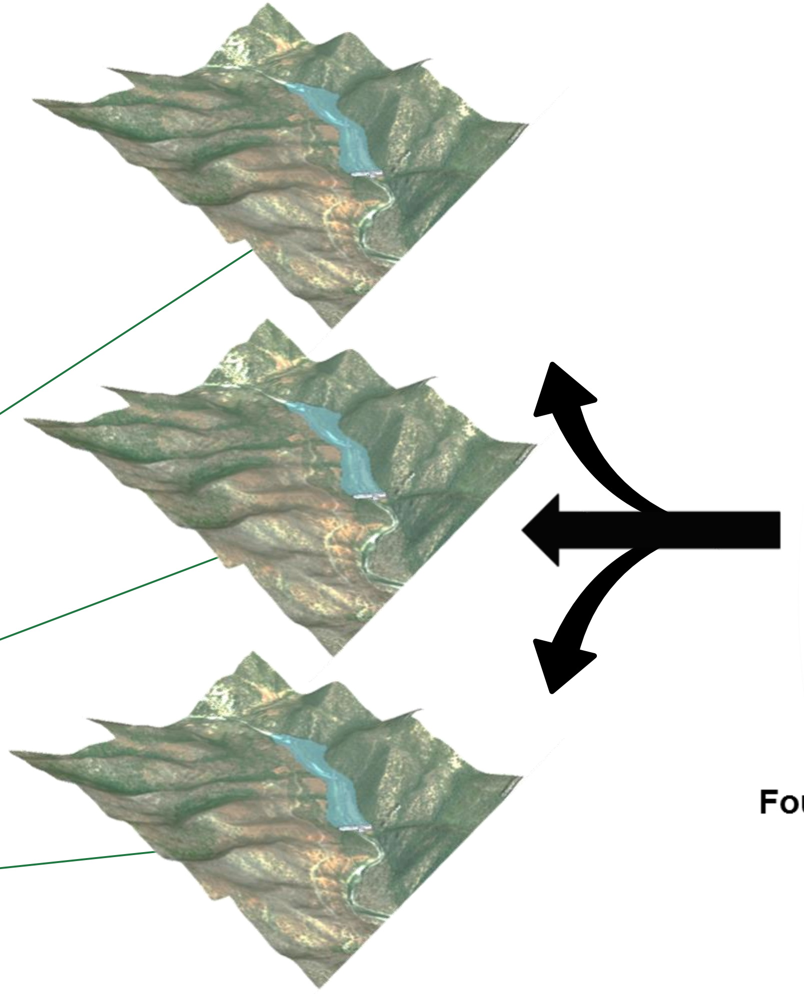
Clusters of similar sites



● = similar:

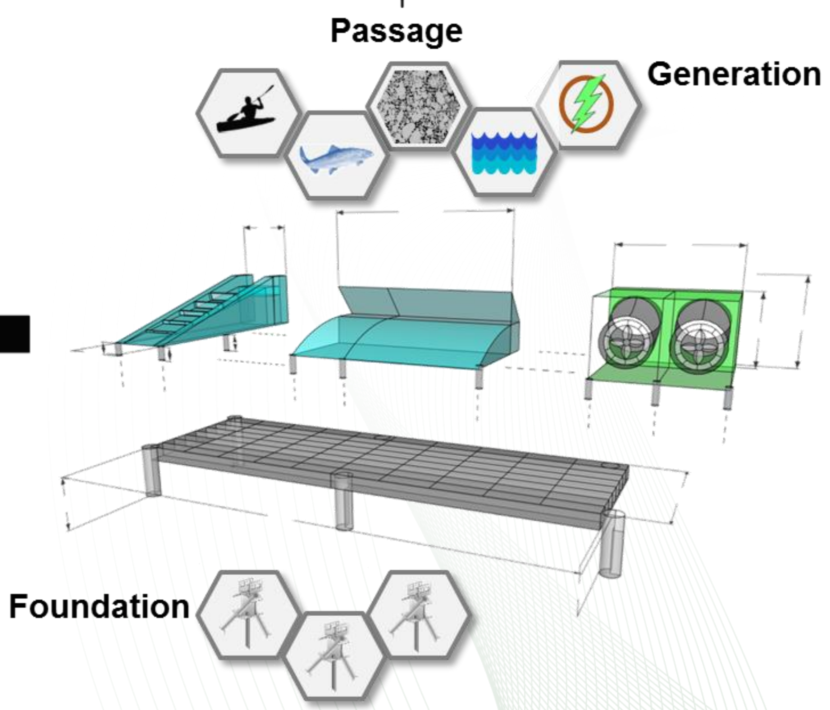
energy potential
fish species
recreation use
water quality
sediment
subsurface

Sites in a cluster have common design requirements, may be developed with a suite of standard modular generation, passage, and foundation technologies



SMH Technology Package

Recreation – Fish – Sediment – Water



Webinar Agenda

Introduction/Motivation

Site Classification

SMH Explorer

Modular Design

5 min → *10 min* → *15 min* → *15 min*

Q&A

15 min