Standard Modular Hydropower Resources Webinar
https://hydropower.ornl.gov/smh
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**
- 5 min

**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

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

https://nhaap.ornl.gov/nsd
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
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)

Megawatts by State: 0 - 3,548

Megawatts by Subbasin: 0 - 813

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.
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

Industriy Innovation

SMH Technology Package
- Recreation – Fish – Sediment – Water

Passage

Generation

Foundation

Standard modular facility concept design. Note: for visualization purposes only, not meant to convey preferred or ideal design.

Fish
Recreation
Sediment

Water Quality
Energy
Foundation

= similar:
- fish species
- recreation use
- sediment
- water quality
- energy potential
- subsurface
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

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

300,000+ NHD stream reaches with mean annual flow between 50 - 25,000 cfs
Data sources for Site Classification (and SMH Explorer)

<table>
<thead>
<tr>
<th>Dataset</th>
<th>URL</th>
</tr>
</thead>
<tbody>
<tr>
<td>ORNL SMH</td>
<td><a href="https://hydropower.ornl.gov/smh/">https://hydropower.ornl.gov/smh/</a></td>
</tr>
<tr>
<td>ORNL NSD</td>
<td><a href="https://nhaap.ornl.gov/nsd">https://nhaap.ornl.gov/nsd</a></td>
</tr>
<tr>
<td>ORNL NPD</td>
<td><a href="https://nhaap.ornl.gov/content/non-powered-dam-potential">https://nhaap.ornl.gov/content/non-powered-dam-potential</a></td>
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<td>ORNL Environmental Mitigation</td>
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<tr>
<td>ORNL LandCast</td>
<td><a href="http://www.pnas.org/content/112/5/1344">http://www.pnas.org/content/112/5/1344</a></td>
</tr>
<tr>
<td>USGS NHDPlusV2</td>
<td><a href="http://www.horizon-systems.com/nhdplus/NHDPlusV2_home.php">http://www.horizon-systems.com/nhdplus/NHDPlusV2_home.php</a></td>
</tr>
<tr>
<td>USGS WBD</td>
<td><a href="https://nhd.usgs.gov/wbd.html">https://nhd.usgs.gov/wbd.html</a></td>
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<tr>
<td>USGS WRD NSDI</td>
<td><a href="https://water.usgs.gov/lookup/getgislst">https://water.usgs.gov/lookup/getgislst</a></td>
</tr>
<tr>
<td>USGS seismic hazard maps</td>
<td><a href="https://earthquake.usgs.gov/hazards/hazmaps/">https://earthquake.usgs.gov/hazards/hazmaps/</a></td>
</tr>
<tr>
<td>USGS geologic maps</td>
<td><a href="https://mrdata.usgs.gov/geology/state/">https://mrdata.usgs.gov/geology/state/</a></td>
</tr>
<tr>
<td>StreamCat</td>
<td><a href="https://www.epa.gov/national-aquatic-resource-surveys/streamcat">https://www.epa.gov/national-aquatic-resource-surveys/streamcat</a></td>
</tr>
<tr>
<td>USEPA WQ data</td>
<td><a href="https://www.epa.gov/waterdata/waters-geospatial-data-downloads">https://www.epa.gov/waterdata/waters-geospatial-data-downloads</a></td>
</tr>
<tr>
<td>EIA</td>
<td><a href="https://www.eia.gov/maps/layer_info-m.php">https://www.eia.gov/maps/layer_info-m.php</a></td>
</tr>
<tr>
<td>Yale Climate Opinion Maps</td>
<td><a href="http://climatecommunication.yale.edu/visualizations-data/ycom-us-2016/">http://climatecommunication.yale.edu/visualizations-data/ycom-us-2016/</a></td>
</tr>
<tr>
<td>UTK Hydraulics and Sedimentation Lab</td>
<td><a href="http://hsl.engr.utk.edu/">http://hsl.engr.utk.edu/</a></td>
</tr>
<tr>
<td>Delorme/ORNL</td>
<td><a href="https://developer.garmin.com/datasets/overview">https://developer.garmin.com/datasets/overview</a></td>
</tr>
<tr>
<td>American Whitewater/ORNL</td>
<td><a href="https://www.americanwhitewater.org/">https://www.americanwhitewater.org/</a></td>
</tr>
<tr>
<td>National Rivers Inventory</td>
<td><a href="https://www.nps.gov/subjects/rivers/data.htm">https://www.nps.gov/subjects/rivers/data.htm</a></td>
</tr>
</tbody>
</table>
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

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

### Common migratory species:
- **Ocean-run anadromous species** (clupeids, eels, sturgeons)
- **Inland migratory trout**
- **Mixture of both inland and ocean-run migratory species** (eels, clupeids, salmonids, sturgeon)

### Common physical features:
- **High flow**
- **Moderate flow**
- **Low flow**
- **Prevalent upstream dams**
- **High passage mitigation at existing dams (i.e., mostly intake racks)**
- **Prevalent upstream and downstream dams**
## Fish Passage

<table>
<thead>
<tr>
<th># Reaches</th>
<th>Defining characteristics</th>
<th>Locale</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Potamodromous salmonids, high downstream dam count, high existing passage mitigation</td>
<td>Appalachia, Texas, Northwest</td>
</tr>
<tr>
<td>2</td>
<td>High other potamodromous species, low anadromous species</td>
<td>Great Lakes, upper Midwest, upper Ohio River, Gulf Coast</td>
</tr>
<tr>
<td>3</td>
<td>Anadromous salmonids, potamodromous salmonids, low upstream and downstream dam count, high existing passage mitigation, anadromous lampreys</td>
<td>Pacific Northwest</td>
</tr>
<tr>
<td>4</td>
<td>Some anadromous clupeids, high upstream and downstream dam count, low MAF</td>
<td>South central, New England</td>
</tr>
<tr>
<td>5</td>
<td>Low existing passage mitigation, low or absent salmonid presence, eels, low downstream dam count</td>
<td>Lower Mississippi River drainage</td>
</tr>
<tr>
<td>6</td>
<td>High MAF, inland sturgeon, and other inland species</td>
<td>Scattered nationally</td>
</tr>
<tr>
<td>7</td>
<td>Very low numbers of all major migratory species, low existing passage mitigation</td>
<td>Scattered nationally</td>
</tr>
<tr>
<td>8</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>9</td>
<td>Inland sturgeons and other inland potamodromous species, low downstream dam count, low existing passage mitigation, low anadromous species</td>
<td>Upper Mississippi River drainage</td>
</tr>
<tr>
<td>10</td>
<td>Anadromous clupeids, ocean-run sturgeons, eels, high upstream and downstream dam count</td>
<td>Atlantic Coast</td>
</tr>
</tbody>
</table>
## Recreation

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

### Defining characteristics

<table>
<thead>
<tr>
<th># Reaches</th>
<th>Defining characteristics</th>
<th>Locale</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Low runoff, variable flow</td>
<td>Mountain west and plains</td>
</tr>
<tr>
<td>2</td>
<td>Mod &amp; steady flow, low ag, high runoff, high velocity</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Low velocity, clay</td>
<td>Upper midwest</td>
</tr>
<tr>
<td>4</td>
<td>Agricultural, slow, high erodibility, clay</td>
<td>Midsouth</td>
</tr>
<tr>
<td>5</td>
<td>Small streams, slow, urban</td>
<td>National</td>
</tr>
<tr>
<td>6</td>
<td>Forested, low ag</td>
<td>Northeast, northwest, Appalachians</td>
</tr>
<tr>
<td>7</td>
<td>Rocky streams, forested</td>
<td>National</td>
</tr>
<tr>
<td>8</td>
<td>Sandy, low erosion, slow</td>
<td>Southeast, Great Lakes</td>
</tr>
<tr>
<td>9</td>
<td>Large rivers, high velocity</td>
<td>National</td>
</tr>
<tr>
<td>10</td>
<td>Forested, low ag, high runoff, steady flow</td>
<td>Pacific northwest</td>
</tr>
<tr>
<td>#</td>
<td>Reaches</td>
<td>Defining characteristics</td>
</tr>
<tr>
<td>---</td>
<td>---------</td>
<td>--------------------------</td>
</tr>
<tr>
<td>1</td>
<td>37,500</td>
<td>low Q, high baseflow, high seasonal var. (snow melt)</td>
</tr>
<tr>
<td>2</td>
<td>10,000</td>
<td>med Q, steep grade, high baseflow, low seasonal var.</td>
</tr>
<tr>
<td>3</td>
<td>21,500</td>
<td>med Q, high velocity,</td>
</tr>
<tr>
<td>4</td>
<td>9,000</td>
<td>med Q, low grade, low baseflow,</td>
</tr>
<tr>
<td>5</td>
<td>18,000</td>
<td>low Q, low grade, low baseflow, low velocity, high seasonal var.</td>
</tr>
<tr>
<td>6</td>
<td>69,000</td>
<td>low Q, low grade, low baseflow, low velocity,</td>
</tr>
<tr>
<td>7</td>
<td>2,700</td>
<td>low Q, steep grade, high baseflow,</td>
</tr>
<tr>
<td>8</td>
<td>86,500</td>
<td>low Q, low velocity,</td>
</tr>
<tr>
<td>9</td>
<td>20</td>
<td>med Q, very steep grade(?), high velocity,</td>
</tr>
<tr>
<td>10</td>
<td>9,500</td>
<td>high Q, low grade,</td>
</tr>
</tbody>
</table>
Water Quality

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

### NHD reaches

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

- Technical report
- Other ORNL websites
- Visualization enhancement tools

Query tools

Layer attributes
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

1. Click on ‘Select’ query tool
2. Click on ‘Select’ box within query tool
3. Left click and drag the mouse to select a state and let go to finish. Adjacent states can be selected by holding down the Shift key and left clicking/dragging simultaneously.

1. Click on ‘Query’ tool
2. Scroll through ‘Query criteria’

1. Enter lower (500) and upper (10000) bounds on mean annual flow
2. Scroll down and enter lower (1) and upper (2) bounds on ocean eel/lamprey species observed in HUC8 watershed

Box is expandable
Use Case 1 continued

1. Click ‘…’
2. Click ‘Export to CSV file’
3. Data from attribute table will be exported

Potential application space for module

Stream-reaches that meet filter criteria (all yellow reaches)

Summary of each stream-reach

Click ‘…’ then View in Attribute Table to view a table of all individual stream-reaches
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.
Use Case 2: Project developer assessing module need at site and identifying similar sites

1. Input “42.629769, -111.609398” and hit enter

2. Left click on flow line

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

5 min

Introduction/Motivation

10 min

Site Classification

15 min

SMH Explorer

15 min

Modular Design

Q&A

15 min
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

Research and definition  Design and development  Manufacturing and testing  Evaluation

ORNL work to date along new design continuum

For more details and full design envelope specification for each module see:
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.)
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

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

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

Passage flow velocity as function of design discharge and geometry

(NRCS 2007) (Katopodis 1992)
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

Species of interest and flow data

Develop concept that meets objectives, requirements, and constraints

Modular fish ladder

Identify functional relationships

Sizing and hydraulics technical guidance

Use functional relationships to estimate performance

Hydraulics, design flow, attraction flow, footprint, cost, etc.

Commence preliminary design iteration
generate hydroelectric power from flowing water under pressure

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

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)
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
  - Flow and head/stage data

Develop concept that meets objectives, requirements, and constraints
- Generation module with intake, trash rack, runner, generator, shutoff, and outlet

Identify functional relationships
- Efficiency curves, hill charts, specific speed, etc.

Use functional relationships to estimate performance
- Installed capacity, power duration curve, footprint, cost, etc.

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
Standard Modular Hydropower Concept Recap

Data aggregation and site classification

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
- Passage
- Generation
- Foundation
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