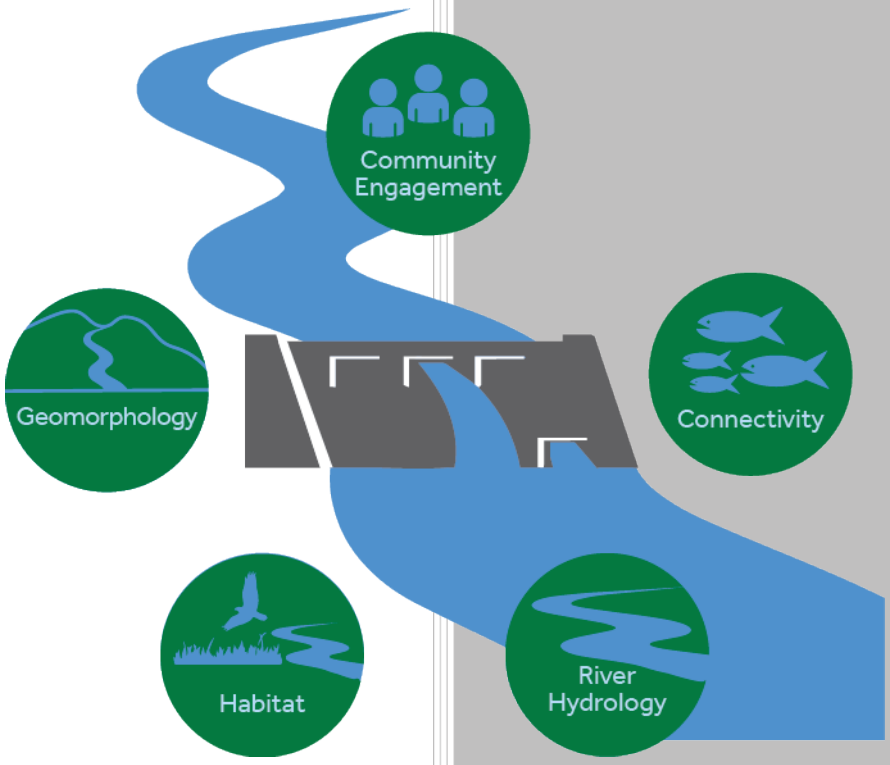
ORNL/TM-2018/818

Catalog of Environmental Metrics for Hydropower



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June 2018

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE US DEPARTMENT OF ENERGY

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ORNL Environmental Science Division

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1. INTRODUCTION

1.1 ORIGIN & METHOD / PROPOSAL EVOLUTION

The catalog evolved as a project from discussions on hydropower new stream reach development and sustainability. While sustainability includes balancing economic, social and environmental aspects, this catalog focuses on environmental metrics used in assessing the environmental effects of new hydropower development. Environmental effects in this context refers to the effects on the physical and ecological functions of streams and biota. This catalog of metrics, and metric methodology will enable stakeholders to define, assess, and communicate their own concepts of environmental sustainability with efficacy, clarity, and transparency.

Cataloging environmental metrics should not be confused with the outcomes of existing regulatory processes since those Acts stipulate what agencies must do, must not do, and may choose to do based upon a thorough assessment of the project's potential impacts and developed protection, mitigation and enhancement measures. Environmental metrics, on the other hand, represent the most fundamental levels of environmental information, upon which the procedural stipulations mentioned above are based. Examining the raw information underlying the basis of existing protocols, certifications, regulations, and their outcomes is a level of transparency needed to determine the current state of practice and the adequacy of those processes. Environmental metrics also enable stakeholder input into regulatory decision-making that often results in trade-offs. This Environmental Metrics for Hydropower project will translate science findings into useful metrics, thereby enabling stakeholders and agencies to be more efficient, concise, transparent, and collaborative in expressing their priorities and concerns about hydropower development.

The overall long-term intent of the project is to identify a measurable, repeatable, and broadly understandable suite of metrics for quantifying the environmental effects of hydropower. This project will also document the variability of metrics used to evaluate environmental impact. The importance of these metrics is to help identify and quantify the benefits and cost options during project development.

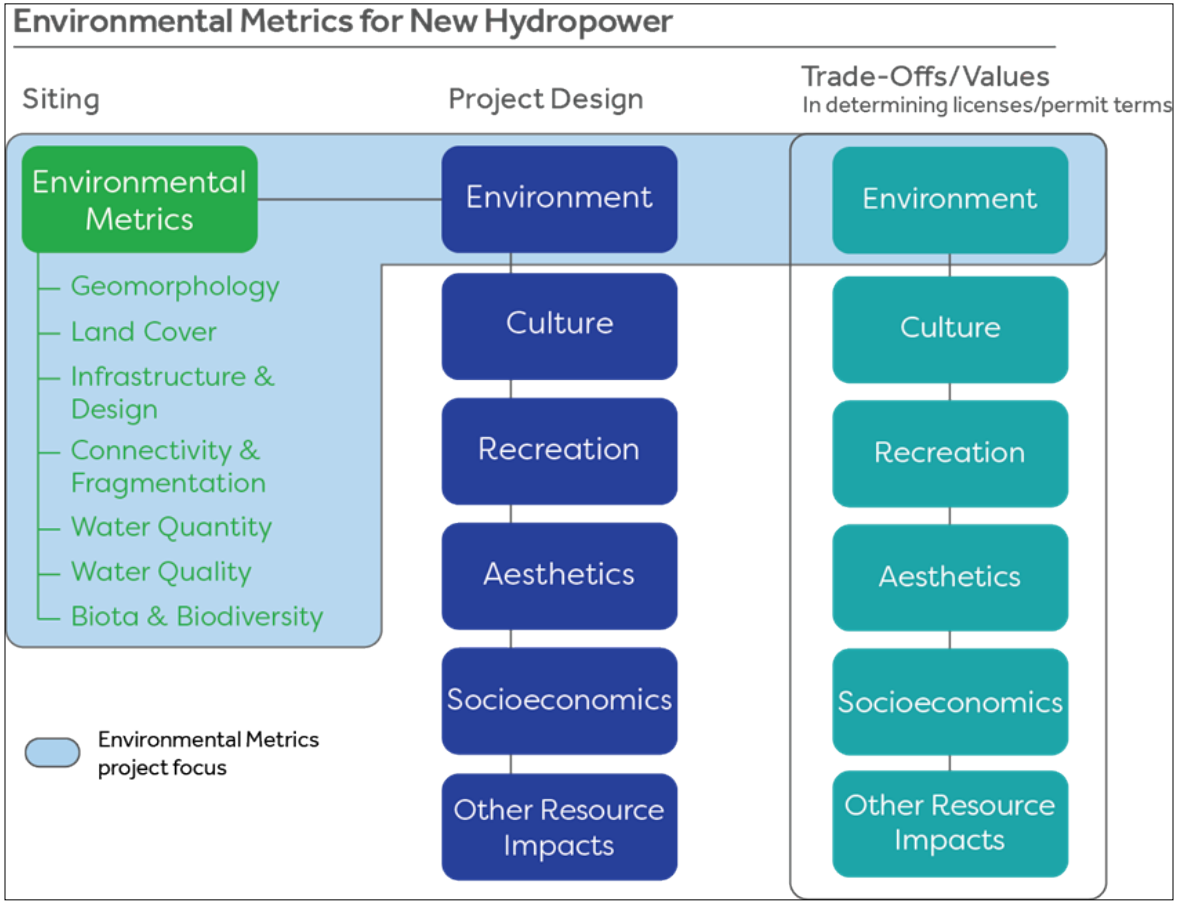


Figure 1 - Environmental metrics relate to only a portion of the rigorous process of hydropower design and permitting, which also involves socioeconomic considerations.

Therefore, these metrics must have measurable units that are agreed upon and can be consistently applied across the U.S.

1.2 CATEGORIES OF METRICS

In the development of standard communications avenue for this study a shared terminology document (Pracheil et al. 2016) was developed that is more than a simple glossary. To capture the general environmental concepts that govern river ecology, enable thematic analysis and consistent visualization of findings, the Environmental Metrics for Hydropower (EMH) project classifies information into 7 categories which are applicable across siting, project design and permitting (Figure 1). These 7 categories are Geomorphology, Land Cover, Infrastructure and Design, Connectivity and Fragmentation, Water Quantity, Water Quality and Biota and Biodiversity. As metrics were identified, they were assigned one category.

1. **Geomorphology** –Geomorphology is the dynamic evolution of topographic and bathymetric features created within an ecosystem. Hydropower development can disrupt a river system's geomorphologic equilibrium through altered sediment and flow regimes. These changes have the potential to impact the availability and quality of habitat for plants and animals within the system.
2. **Land cover**— Land cover type (the physical material on the earth's surface) is an important measure of ecosystem health because it influences many other environmental properties ranging from river and floodplain sedimentation rates to fragmentation of habitats and wildlife populations at scales ranging from site to landscape. Land cover changes can be used to more-fully describe ecosystem changes associated with hydropower development, such as increases in wetted surface from reservoir formation, and fragmentation of the surrounding landscape through installation of supporting infrastructure (e.g., transmission lines, roads). Land cover characterization pre- and post-hydropower development is an important component of understanding hydropower-affected ecosystems.
3. **Infrastructure and Design**–Hydropower infrastructure involves construction of structures in-stream (for impounding water and generating power) and in adjacent riparian and terrestrial lands (for transmitting power and accessing the site). The selection of hydropower equipment, associated infrastructure and management practices can bear directly and indirectly on the other six Science Core Concepts through a variety of factors such as increased land cover fragmentation for running transmission lines, exposure of animals and humans to electromagnetic fields, changes in the volume and timing of water releases, and the use of industrial lubricants needed to keep hydropower turbines properly working.
4. **Connectivity and Fragmentation**— Ecosystem connectivity (the degree to which a land cover type or ecosystem maintains continuity) and fragmentation (the degree to which an ecosystem or land cover type is disconnected) can affect the habitat quantity and quality for organisms in an ecosystem. Dams and their associated infrastructure can disrupt aquatic, riparian, and terrestrial connectivity, as well as groundwater connectivity, all of which can directly impact biota. Quantifying connectivity changes is therefore important for a full accounting of the environmental effects of hydropower.
5. **Water Quantity** –Water quantity refers to the amount of water found in-stream, in a reservoir or in groundwater stores and includes flow magnitude, duration, frequency, timing, and rate-of-change of flows. Hydropower development can alter the quantity of water in several ways through water storage in reservoirs, increased evaporation rates, change availability of in-channel water downstream of a dam, as well as change the quantity of ground water both upstream and downstream of dams. Because hydropower systems may be operated to fill a variety of purposes, changes to water quantity may occur at a variety of temporal scales ranging from diel to annual. Changes to water quantity can ultimately affect human and wildlife populations through altered water supplies for a variety of end uses (e.g., agricultural, drinking, municipal, industrial, recreational) and through changes in habitat availability.
6. **Water Quality**—Water quality characteristics such as temperature and concentrations of dissolved oxygen, velocity, nutrients and contaminants can be directly or indirectly affected by hydropower development and operation. Changes in water quality can adversely affect the health of humans and wildlife.
7. **Biota and biodiversity**—The types of plant and animal species found in a watershed, as well as their absolute abundance and relative abundance to each other, reflect the overall health of an ecosystem. Shifts in aquatic, riparian and terrestrial populations and communities have been linked to several aspects of hydropower construction and operation, including decreased longitudinal connectivity and changes in flow velocities in rivers, inundation of uplands

upstream of dams, changes in ground water depth both up and downstream of dams, and changes in sediment and flow regimes. Identifying metrics to accurately assess population and community changes are essential to understanding the environmental effects of hydropower.

1.3 METRIC TYPES

It is recognized that different metrics require different levels of analysis and interpretation. Throughout this study metrics are assigned a type that best describes this level of analysis. These are broken into three types, measurement, statistic and indicator.

Additional attributes were assigned including the type of metric:

- **Measure**—a direct measurement of environmental phenomenon (e.g., temperature readings, species counts)
- **Statistic**—a mathematical summarization of collected environmental measures (e.g., hydrograph)
- **Indicator**—a measure or statistic whose values have been used to indicate positive or negative movement toward or away from a goal established by stakeholders (e.g., reforestation)

A measurement with a threshold should be a red flag to look for additional information/rationale behind it (i.e., we need to know the rationale taken to raise the measurement to the level of an indicator).

Figure 2 - Representation of metric types: measure, statistic, and indicator

1.4 APPROACH

Documenting the metrics used to describe the environmental effects of hydropower is a difficult task, as the 'environment' includes aquatic and terrestrial ecosystems and spans multiple disciplines of environmental and ecological sciences. Executing this task must start at a very broad level, principally coming to a common understanding of what the "environment" includes and a common terminology of how we go about describing it. Hence, an organizational framework is required to catalog environmental metrics across the many dimensions of the environmental science space. In developing the framework for the metric extraction, ORNL developed a working document titled *Environmental Metrics for New Hydropower: Terminology and Categories (Pracheil, et. al. 2016)* which is more than a simple glossary. It specifies and categorizes environmental metrics (Section I), defines relevant environmental terminology (Section II), and defines general ecological concepts (Section III) needed to foster clear communication about environmental issues pertaining to hydropower development and operation.

Environmental metrics were extracted from multiple sources: (1) International Hydropower Association (IHA) Hydropower Sustainability Assessment Protocol (HSAP) (2) Low Impact Hydropower Institute (LIHI) (3) Federal Energy Regulatory Commission (FERC) and (4) Systematic review of the peer-reviewed scholarly literature using guidelines established by the Center for Environmental Evidence (CEE 2013) The environmental metrics used by hydropower certificatory bodies (LIHI, IHA) and the current U.S hydropower regulatory domain (FERC licenses) including their satisfaction of other pieces of the current hydropower regulation such as National Environmental Policy Act (NEPA) and Council on Environmental Quality (CEQ), which require several metrics to be evaluated. Because the dimensions of environmental information can be described in multiple levels of detail, a hierarchical template was developed to organize the catalog of metrics and their attributes. This included the development of 7 main environmental categories, which are divided into 45 more specific parameter categories, in addition to a number of attributes describing the hydropower project and systems under consideration for each metric. Additionally, a template was devised to describe the nature of how metrics convey information, such as in raw measurements, statistical summarization, or in the form of indicators that inherently contain heuristic values.

The process of extracting metrics for each of these sectors is provided in more detail below.

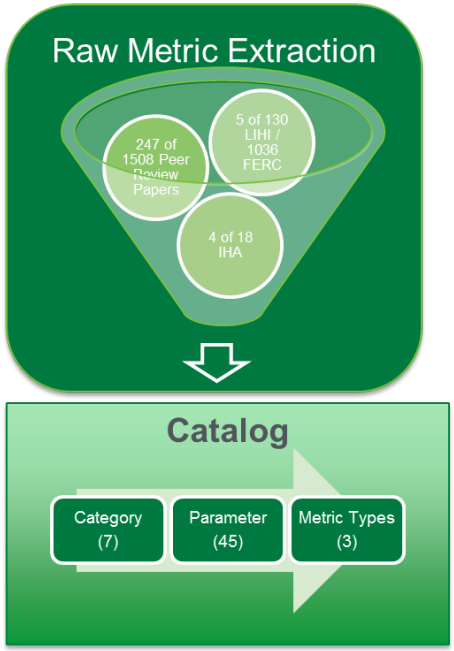


Figure 3- Raw metric extraction to Catalog

1.4.1 International Hydropower Association (IHA) Projects

Figure 4 - Logo for IHA International Hydropower Sustainability Assessment Protocol

Environmental metrics were captured from a subset of 13 hydropower projects that have been reviewed and published using the International Hydropower Association's (IHA's) Hydropower Sustainability Assessment Protocol (HSAP). All 13 published IHA HSAP projects were reviewed for sustainability scores and gaps, dam locations were determined using Google Earth, and a crosswalk chart of definitions was developed to facilitate understanding of the different sustainability topics which apply at each of the four stages of HSAP application (i.e., Early stage, Preparation stage, Implementation stage, or Operation stage).

An initial subset of IHA projects was selected to span the globe, as shown in Figure 5. Table 1 lists details of the 4 IHA projects selected for detailed environmental metrics extraction.

Table 1 - List of IHA hydropower projects reviewed for environmental metrics

Hydropower Project	Country	River	Owner	Capacity (MW)	IHA HSAP Protocol Stage	Metrics
Chaglla	Peru	Huallaga	Empresa de Generación Huallaga S.A.	456	Implementation	43
Kabeli A	Nepal	Kabeli	Kabeli Energy Limited	37.6	Preparation	40
Walchensee-kraftverk	Germany	Isar	E.ON Hydro Fleet	124	Operation	8
Trevallyn	Australia	Esk	Hydro Tasmania	96	Operation	16

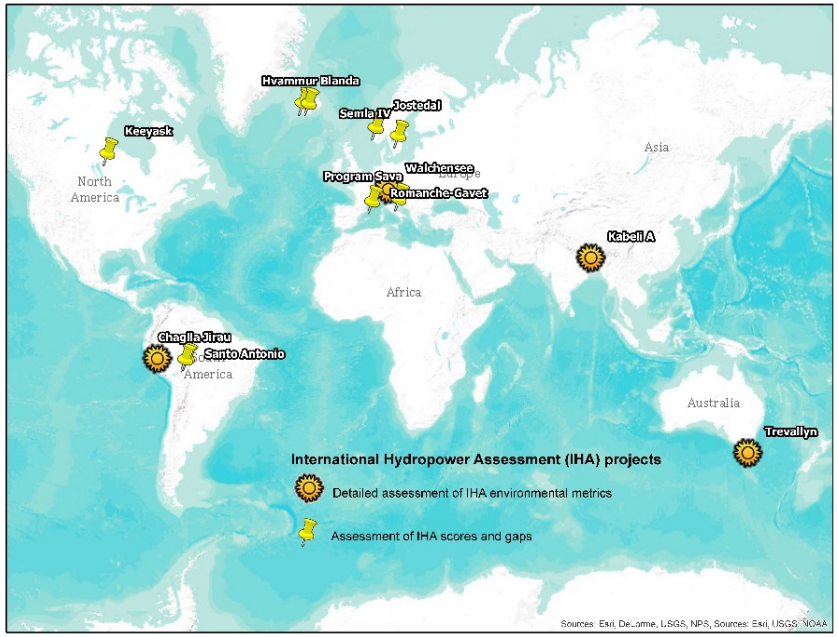


Figure 5 - International Hydropower Sustainability Assessment projects

Three elements to consider in an IHA Hydropower Sustainability Assessment:

1. "The graded performance within each sustainability topic provides the opportunity to promote structured continuous improvement." (HSAP Nov2010)
2. "The HSAP should be applied in a collaborative way, to ensure the best availability of information and points of view. The development and evaluation of a hydropower project will involve many actors with different roles and responsibilities. It is recognized that both development and operation may involve public entities, private companies or combined partnerships, and responsibilities may change as the project progresses through its life cycle." (HSAP Nov2010)
3. "The terms and conditions define an official assessment as one which: (1) Is carried out by an independent accredited assessor; (2) Involves the principal organisation responsible for the project [at the current stage], demonstrated by their written support; and (3) Meets any other guidelines for official assessment published by the Hydropower Sustainability Assessment Council." (HSAP Nov2010)

Each HSAP sustainability score reflects the graded performance of the project from lowest level (1) to highest level (5) relative to good and best practices across the industry. The recorded scores and gaps are meant to provide the opportunity to promote structured continuous improvement and are not intended for pass/fail determination. Figure 6 provides an example of how all of the published IHA

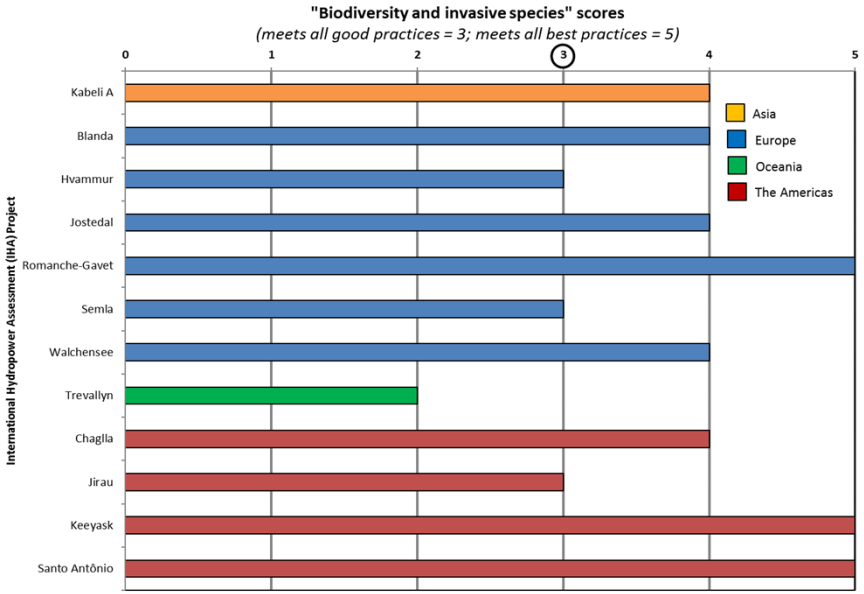


Figure 6 - IHA sustainability protocol 'Biodiversity and Invasive Species' scores

projects scored with regard to the 'Biodiversity and invasive species' sustainability topic. For this topic, only one project (Trevallyn) showed a significant gap relative to good practices. Three projects (Romanche-Gavet, Keeyask, and Santo Antônio) were found to meet the best possible practices with regard to biodiversity.

Disentangling environmental metrics from socioeconomic metrics proved difficult due to IHA's integrated evaluation approach.
Environmental metrics were found to be closely associated with these HSAP sustainability topic areas:

- Biodiversity and invasive species
- Downstream flow regimes
- Erosion and sedimentation
- Reservoir planning
- Waste, noise and air quality
- Water quality

A total of 100 environmental metrics corresponding to all of the 7 EMH Categories were gleaned from the analysis of the four 4 IHA projects selected for detailed analysis. An additional 7 metrics not pertaining to the EMH categories were also captured in the metrics database for future consideration. These 7 metrics related to air quality, noise, solid waste generation, soil contamination and electromagnetism.

1.4.2 Low Impact Hydropower Institute (LIHI)/ Federal Energy Regulatory Commission (FERC)

In order to provide a sub-sample of environmental metrics applied within LIHI protocols and FERC regulations, five U.S. non-federal hydropower projects were chosen that were both (a) LIHI certified, and (b) have recently undergone FERC relicensing (Figure 7). Projects were selected to represent different geographical regions of the U.S. and a diversity in project sizes (megawatt capacity and infrastructure). Selected projects and their characteristics are listed in Table 1.

For each project, all LIHI documentation was openly available through the institute's webpage and reviewed. The structure of the LIHI certification process is defined by eight social and environmental impact criteria (listed below), each addressed through a series of goal statements that define the purpose or objective that must be satisfied (Sale et al. 2016).

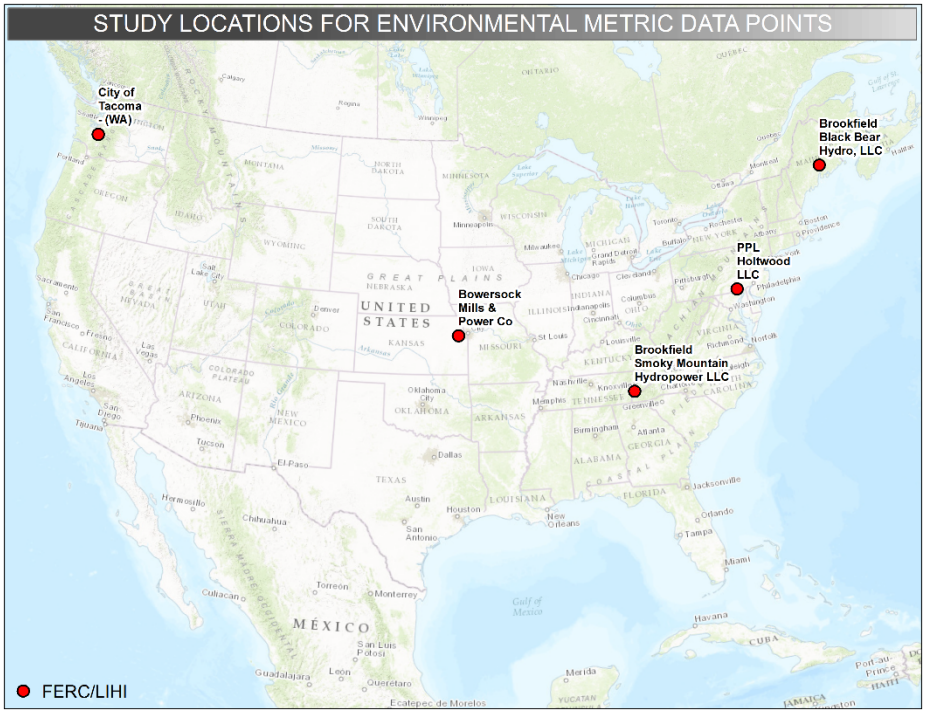
LIHI impact criteria

- Ecological Flow Regimes
- Water Quality Protection
- Upstream Fish Passage
- Downstream Fish Passage and Protection
- Watershed and Shoreline Protection
- Threatened and Endangered Species Protection
- Cultural and Historic Resource Protection**
- Recreational Resources**

**Not addressed

A series of alternative standards are provided

ORNL Catalog of Environmental M



by which each criteria goal can be met. After consultation with LIHI staff, applicants prepare an application, which includes a description of project facilities and a standardized LIHI questionnaire. The questionnaire is structured to document how the applicant has addressed each of the eight criteria through a standard(s). Additional supporting documents, such as fish passage plans, monitoring plans, and maps of facilities are provided.

For the same projects, FERC orders issuing new licenses and notices of environmental assessments (including the environmental impact assessment) were obtained from FERC e-library and reviewed. Typically, FERC orders are structured to provide a description of project facilities, followed by discussion of major environmental elements and stakeholder concerns, and then subsequent articles specifying the approved facilities and operations, including how environmental impacts are addressed. For a review of the detail of environmental information (including mitigation requirements) provided by FERC order approvals, please see Schramm et al. (2016). Because FERC specifies facility dimensions and capacities (e.g., dam storage) as apart of licensed projects, these elements are interpreted as metrics describing environmental impact along with traditional metrics (e.g., water temperature). For instance, if the licensee increases the capacity of a project, this will likely require re-opening a license, as potential subsequent environmental impacts must be reassessed.

Figure 7. Locations of non-Federal U.S. Hydropower projects certified by LIHI and recently relicensed by FERC.

Table 2. List of five FERC/LIHI projects reviewed for environmental metrics*

Hydropower Project	FERC No.	LIHI No.	U.S. State	River	Owner	Capacity (MW)	Average Annual Gener-ation (MWh)	Metrics
Bowersock Project	13526	15	KS	Kansas River	Bowersock Mills and Power Company	7	32,726	71 FERC, 46 LIHI
Holtwood Hydroelectric Project	1881	116	PA	Susque-hanna River	PPL Holtwood, LLC	252	590,044	132 FERC, 32 LIHI
Milford Hydroelectric Project (includes Milford Dam & Gilmans Falls Dam)	2534	113	ME	Penobscot River; Stillwater Branch	Black Bear Hydro Partners, LLC	7.8	55,186	39 FERC, 16 LIHI
Nisqually Project (includes La Grande and Alder dams)	1862	8	WA	Nisqually River	City of Tacoma	114	573,000	41 LIHI
Smoky Mountain Project	2169	18	NC, TN	Little Tennessee	Brookfield Smoky	376.6	1,361,821	461 FERC, 30

(includes Chilhowee, Calderwood, Cheoah, and Santeetlah dams)	River	Mountain Hydropower LLC	LIHI

*Source Documents:

FERC. (1998). Order Issuing New License. Project No. 2534-005. Bangor-Hydro-Electric Company, Milford Project. April 20, 1998.

FERC. (2004). Notice of availability of environmental assessment. Alcoa Power Generating, Inc. Tapoco Project No. 2169-020. March 15, 2004

FERC. (2004). Notice of availability of final environmental assessment. Bangor-Pacific Hydro Associates. Project No. 2600-056. Final environmental assessment on ammendment of licenses: Veazie Hydroelectric Project, FERC No. 2403-048; Milford Hydroelectric Project, FERC No. 2534-068; West Enfield Hydroelectric Project, FERC No. 2600-056; Medway Hydroelectric Project, FERC No. 2666-023; Stillwater Hydroelectric Project, FERC No. 2712-055. April 18, 2005.

FERC. (2005). Order approving settlement and issuing new license. Project No. 2169-020. Alcoa Power Generating Inc., Tapoco Hydroelectric Project. January 25, 2005.

FERC. (2008). Draft Environmental Impact Statement for License Amendment. Holtwood Hydroelectric Project, FERC Project No. 1881-054, Pennsylvania. July 2008.

FERC. (2009). Order amending license and revising annual charges. Project No. 1881-054. PPL Holtwood, LLC. October 30, 2009.

FERC. (2010). Order Issuing Original License and terminating exemption from license. Project No. 13526-002; Project No. 2644-001. Bowersock Mills and Power Company. August 19, 2010.

FERC. (2010). Notice of availability of environmental assessment. Project No.13526-002. Bowersock Mills and Power Company. August 19, 2010

1.4.3 Peer-Reviewed Scholarly Literature

Using guidelines established by the Center for Environmental Evidence (CEE 2013), a selection of peer-reviewed scholarly literature was identified to extract environmental metrics for Hydropower. The systematic reviews set forth rigorous and repeatable study inclusion criteria and documentation of environmental and hydropower search terms, search dates, and studies included so the review is replicable. This strict methodology of systematic review reduces biases in the studies selected for inclusion. This process has yielded 1,508 papers that are under detailed review extracting relevant environmental metrics. For more detailed explanation of this methodology and search terms please see Appendix A. From these a random subset of 247 papers were chosen to review. Of this subset, 97 articles listed in Appendix B and summarized in Appendix C contained environmental metrics. These environmental metrics were incorporated into a catalog including all information relevant to the metric (e.g., values of the metric, methods of data collection, temporal and spatial resolution).

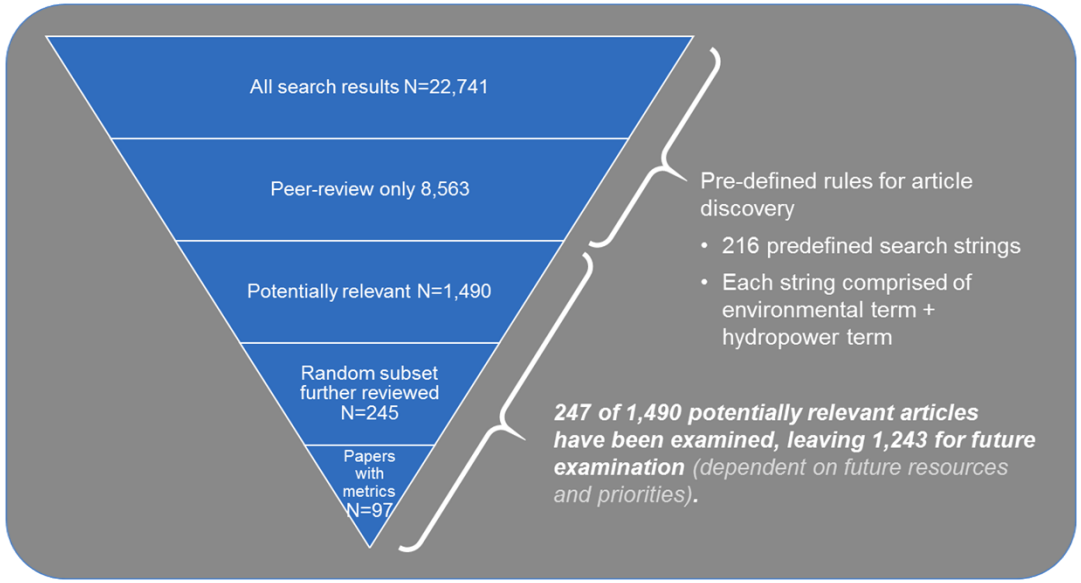


Figure 8 - Systematic Review of Scholarly Peer-Reviewed Literature

1.4.4 Appropriate Use / Intended Use

The definition of combinations of metrics that assess environmental sustainability in specific instances is the purview of stakeholders and is beyond the scope of this study. Follow-on research efforts may advance stakeholder-driven sustainability protocols. This study will not address the role of hydropower development in altering carbon cycling, but the metrics developed in this study may prove useful within that research domain.

2. OTHER TYPES OF INFORMATION EXTRACTED

2.1 PROJECT LOCATION

As environmental metric information was gathered, the site locations of specific studies (Figure 9) were linked in the database to the National Hydropower Asset Assessment Program (NHAAP) database and National Inventory of Dams (NID) for hydropower facilities in the United States and the Global Reservoir and Dam (GRanD) database for non-U.S. hydropower projects. Online searches were conducted for hydropower projects that were not listed in any of these datasets. We also used NHAAP, NID and GRanD obtain ancillary information such as generating capacity, generation, dam characteristics, and reservoir properties:

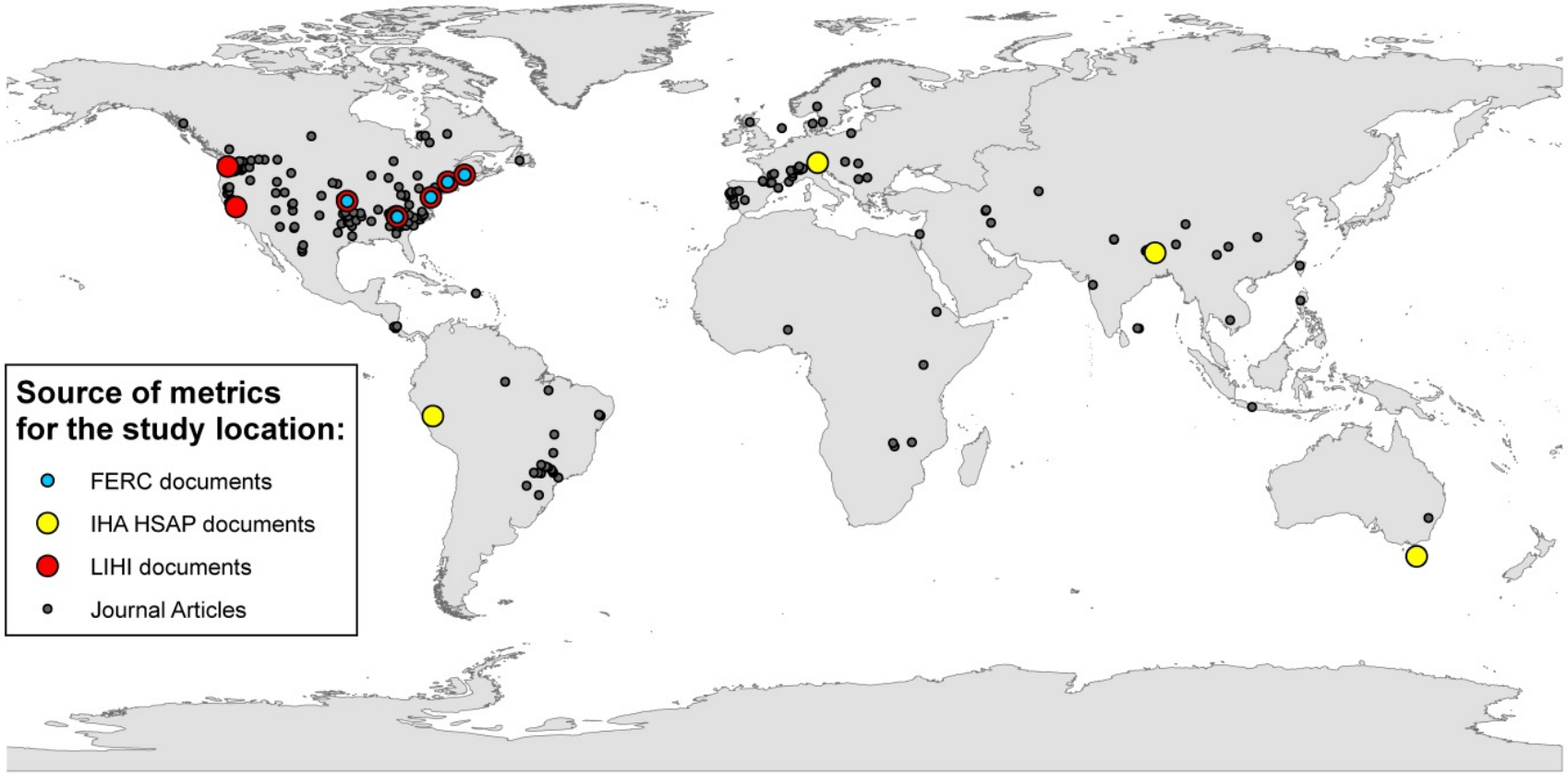


Figure 9 - Map showing the 231 study locations used to collect the metrics recorded for this analysis of the environmental effects of hydropower.

2.2 PROJECT STATUS

Six hydropower life cycles have been defined by the ORNL Standard Modular Hydropower project (*reference)*: (1) initial project determination, (2) permitting & regulatory approval, (3) pre-commissioning activities, (4) construction, (5) operations & maintenance, and (6) decommissioning. During metric extraction, the life cycle stage of the dam at the time that the referenced document was prepared is captured.

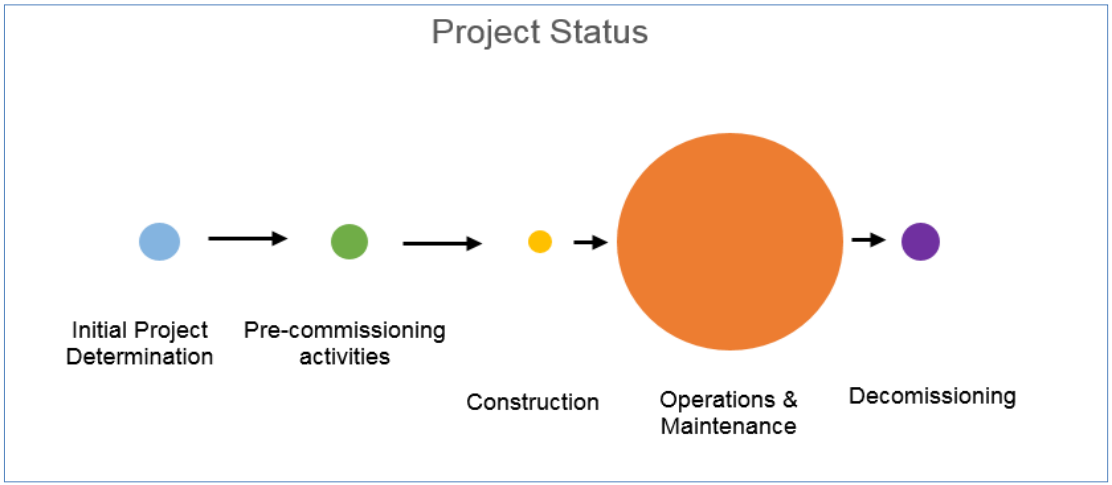


Figure 10 - The represented phases of hydropower development associated with the extracted metrics.

2.3 SPATIAL SCALE

Metrics are applied at different scales, so we recorded spatial information according to the names and definitions shown in Table 2. The frequency of the environmental metrics captured across these different scales is shown in Figure 12.

Table 3 Spatial scales of environmental metrics related to hydropower

Spatial Scale	Definition	Examples
Within dam	Metrics associated with internal dam components	Turbine type
Dam	Metrics associated with the dam itself	Fish passage; Seismic stability
Reservoir	Metrics associated with the impoundment located immediately upstream of the dam	Shoreline erosion; Algal blooms; Siltation rates; Offgassing
River_downstream	Metrics associated with the river downstream of the dam, including the tailwater	Flow rate; Dissolved oxygen levels; Water temperature; Fish counts
River_upstream	Metrics associated with the upstream mainstem and tributaries	Flow rate; Dissolved oxygen levels; Water temperature; Fish counts
Basin	Metrics associated with the watershed in which the hydropower project is located	Water consumption rates; Number of stream tributaries
Landscape	Metrics associated with the terrestrial landscape surrounding the hydropower project	Percent forest cover; Number of road crossings; Miles of transmission lines
Project	Metrics associated with the entire hydropower project (e.g., multiple dams)	Water temperature; Fish condition; Genetic diversity

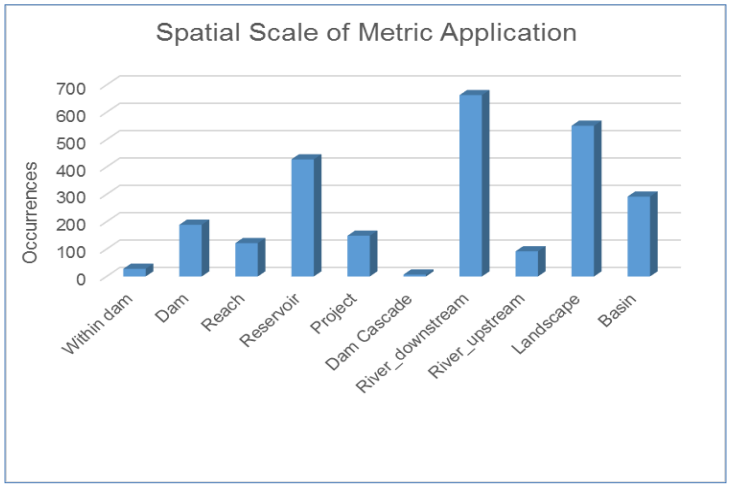


Figure 11 - Spatial scale associated with catalogued metrics.

3. RESULTING SET OF ENVIRONMENTAL METRICS

To capture a broad swath of measurements from multiple sectors concerned with potential hydropower impacts, we based our literature review of environmental metrics on a combination of FERC regulatory documents, LIHI and IHA HSAP certification documents, and peer-reviewed scientific journal articles. Our review of the 117 documents yielded a set of 3183 environmental metrics recorded during a variety of studies related to dams and hydropower projects. These metrics were related to 231 dams and study locations worldwide (Figure 9). Note that several of these points indicate multiple small dams aggregated within a single study. Most of the study sites were in North America (121) and Europe (53), followed by South America (29), Asia (20), Africa (6) and Australia (2). The dams ranged in size from small earthen dams (and even one inflatable dam) built solely for irrigation, flood control, and/or recreational purposes to powered dams with capacities ranging from micro size (i.e., less than 0.1 MW) to as much as 22,500 MW. The literature review included dams assessed across all lifecycle stages (Figure 10), but most of the metrics were collected from dams in the operations and maintenance stage.

The geographic distribution, size and ownership of the U.S. dams captured by this literature review relative to the entire U.S. hydropower fleet is shown in Figure 12. Note that the nonpowered dams captured by the literature review are dams currently managed for flood control, irrigation and/or recreational purposes with no electric power generation as well as a few dams that no longer generate power because they have been decommissioned). This comparison shows that our literature review ended up being biased toward larger, federally owned dams. Small U.S. dams (0.1 to 10 MW) seem to be particularly underrepresented by this dataset of environmental metrics. We were unable to do a similar comparison for the non-U.S. dams due to insufficient hydropower fleet data at the global scale.

A summary of the 3183 captured environmental metrics by category, sector and type is shown in a "dashboard" format in Figure 13. Frequency distributions of the metrics by category and source document type are provided in Figure 14. Irrespective of literature source, most metrics were related to Water Quantity and Water Quality categories, many metrics were related to Biota & Biodiversity, and relatively few metrics were related to the other four categories of Geomorphology, Land Cover, Connectivity & Fragmentation, and Infrastructure & Design. An analysis of the metric distributions broken out for each document type shows that there was not much consistency between the source documents (Figure 14). The journal articles and IHA HSAP documents focused more on Water Quality than Water Quantity. A majority of the Geomorphology metrics came from journal articles and FERC documents, while none were identified in the LIHI documents. Infrastructure & Design metrics were much more prevalent in the FERC and LIHI documents than the journal articles and IHA HSAP documents.

The geographic distribution of the collected metrics by continent and U.S. region is provided in Figure 15. Figure 15A shows a predominance of water quantity and water quality metrics across all continents with a more even mix of the two categories across Europe, South America, Africa and Asia. Given that the pie sizes indicate the relative number of metrics collected across each continent, one can see that the environmental metrics captured by the database are largely from North America and Europe with very few from Oceania. A distribution of the metrics by category across seven U.S. regions reflecting aggregations of river basins mapped by the U.S. Geological Survey (Figure 15B) shows that a substantial number of environmental metrics were captured from documents pertaining to the Southeastern U.S. and that water quantity metrics predominated in all regions except for the Northeast. The Northeastern U.S. showed a more even distribution of metrics across the seven categories, with the largest number of metrics gathered in the category of Biota and Biodiversity.

Examination of the entire set of collected environmental metrics showed coalescence around 45 parameters, or subcategories, of environmental metrics (Table 4) and that most of these subcategories were represented by all three metric types. Details about metrics collected in each of the seven categories are provided in Sections 3.1-3.7.

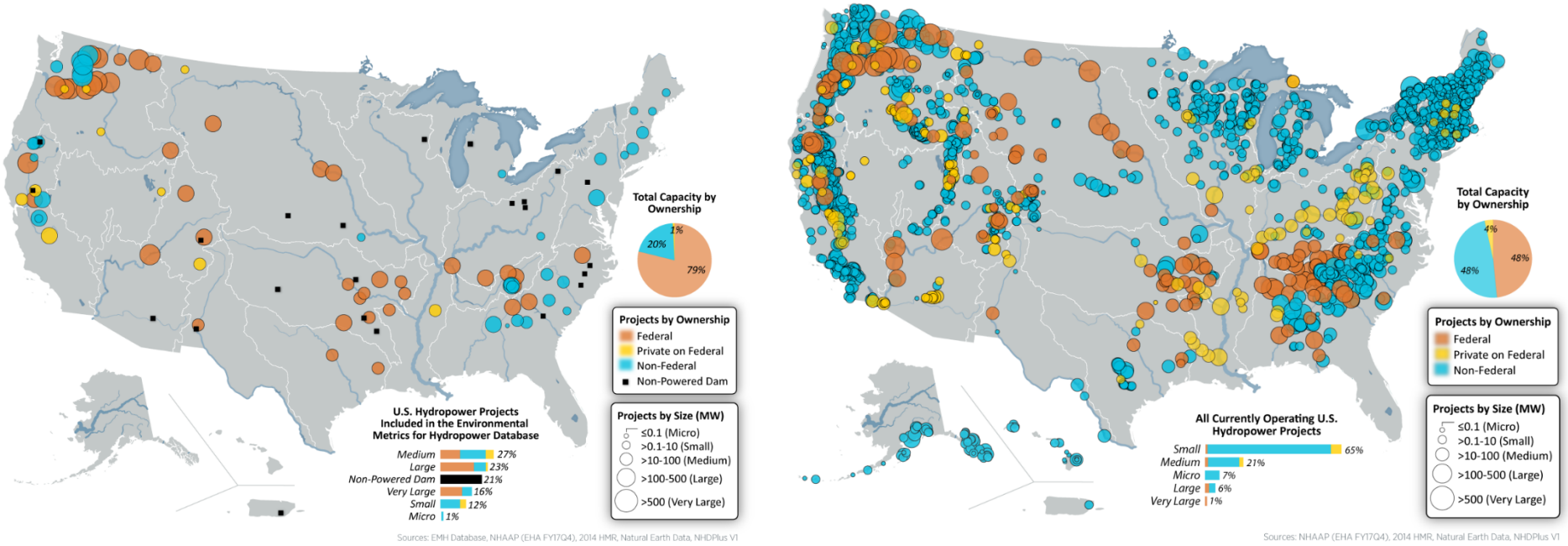


Figure 12 - Size and ownership distribution of U.S. hydropower projects captured by this environmental metrics for hydropower literature review (left) relative to the entire U.S. hydropower fleet (right).

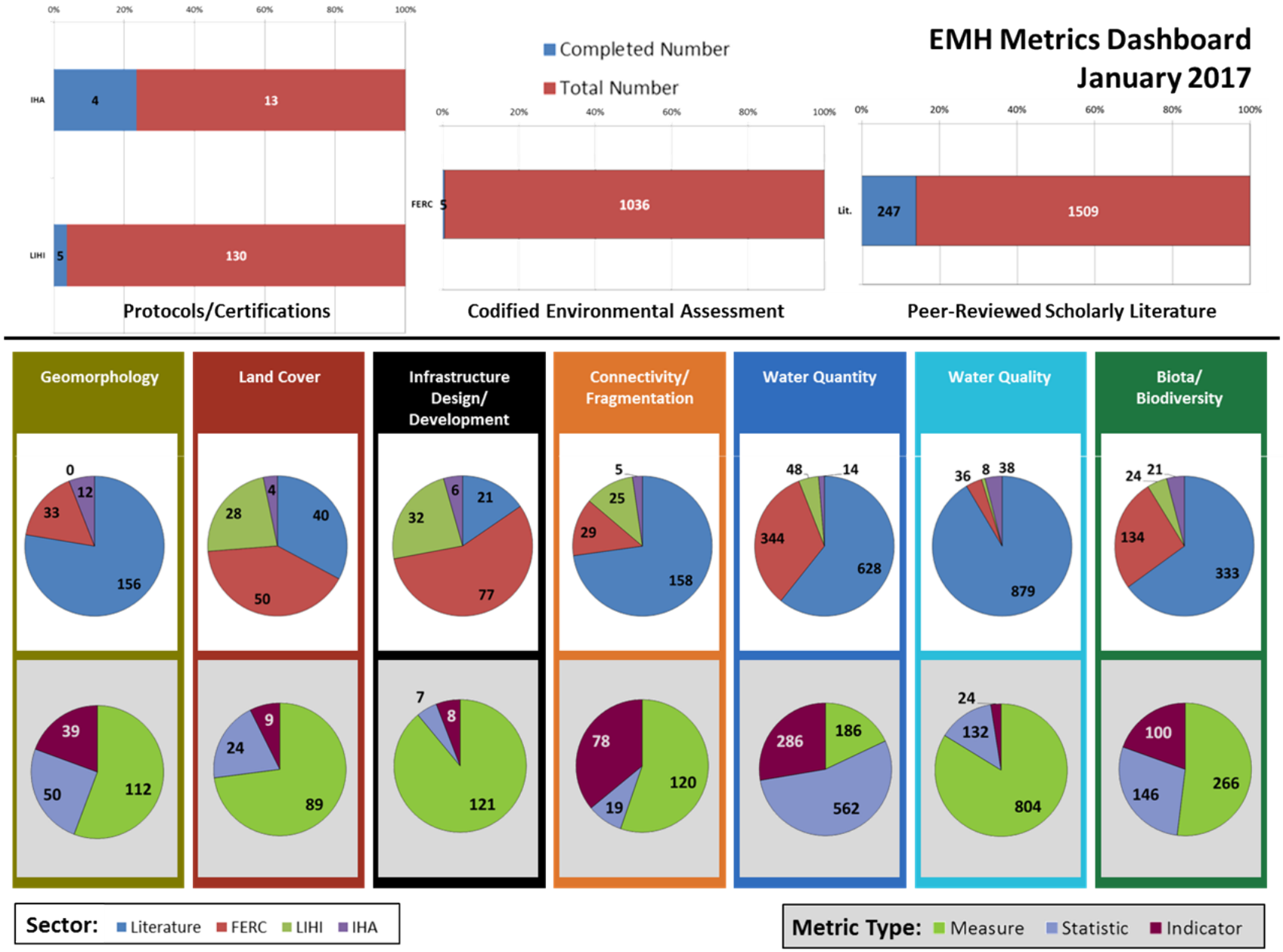


Figure 13 - Summary of captured environmental metrics by category, sector and type.

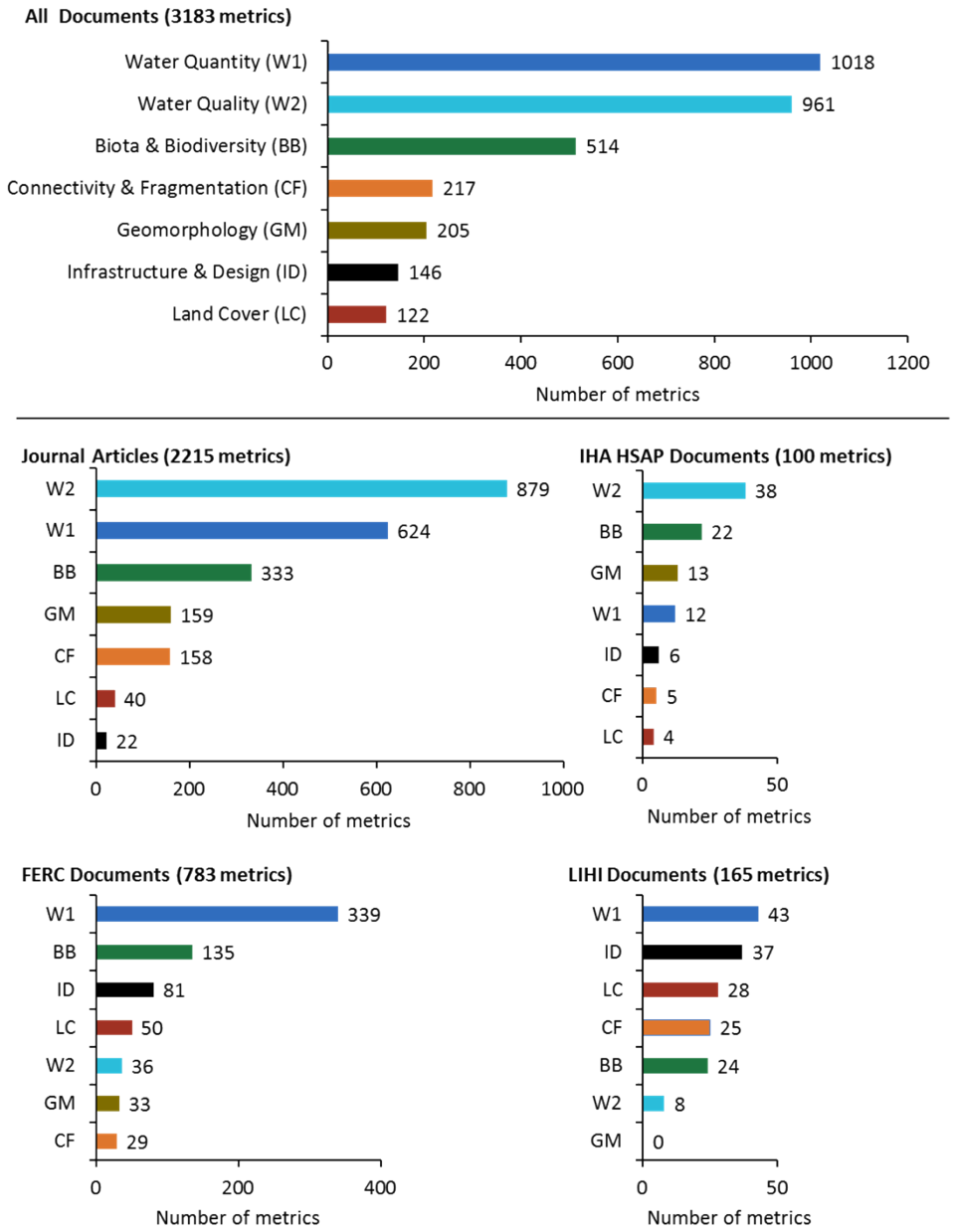


Figure 14- Distribution of the environmental metrics by category and document type

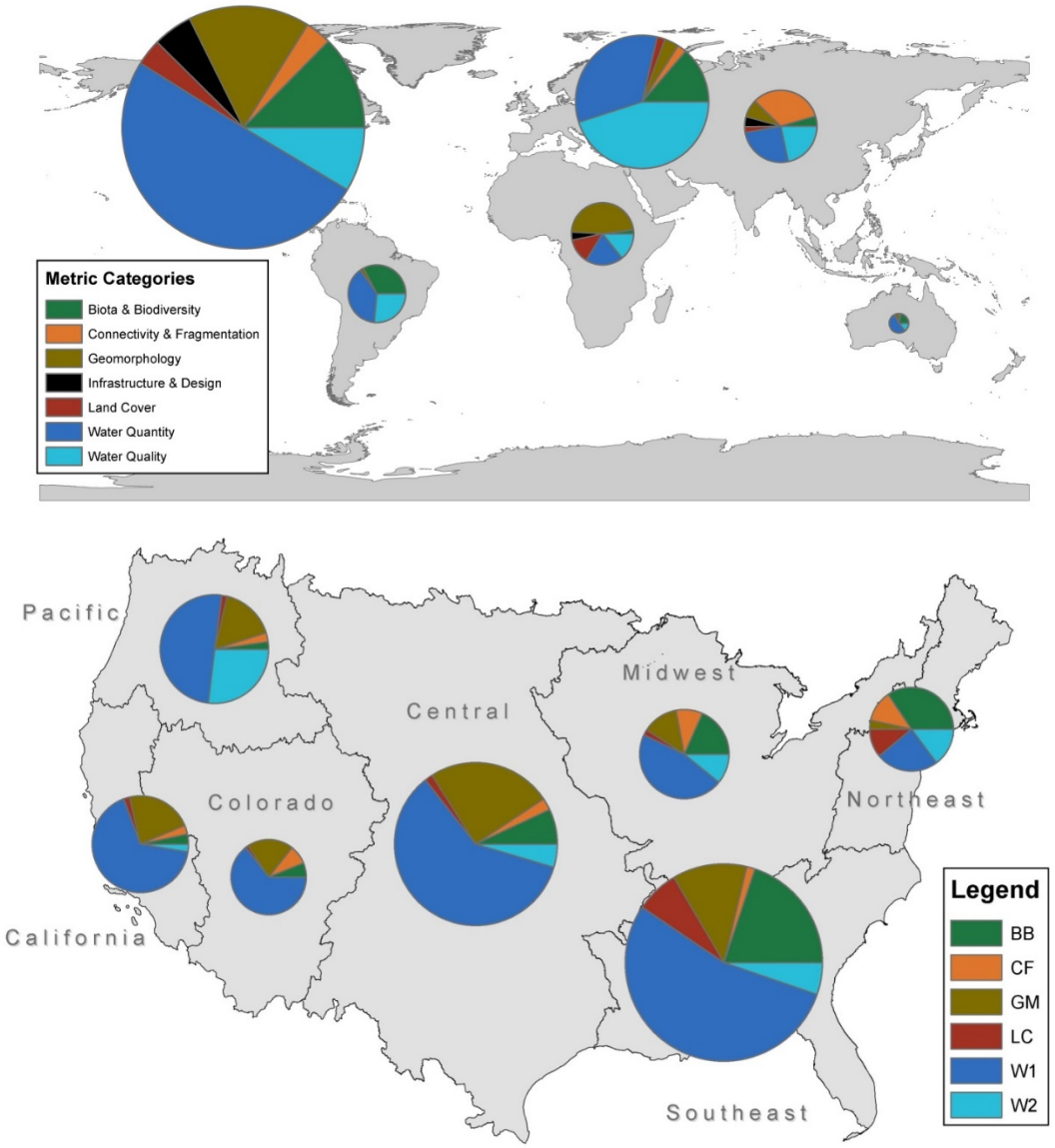


Figure 15- Geographic distribution of the collected environmental metrics by continent (top) and by U.S. region (bottom).

Table 4 Emergent sub-categories (45) of the environmental metrics (3183) collected through this literature review of 117 documents. Metrics totals are also shown by type: M = Measures, S = Statistics, and I = Indicators.

Category	Parameter Name	Parameter Description	M	S	I	Metrics
Biota & Biodiversity	BB_Abundance, density	Count or other measures of organisms per area	42	52	6	100
	BB_Behavior, movement	Behavior of organisms including movement pattern, distance, duration, timing, and frequency	9	2	1	12
	BB_Colonization, extinction	Colonization or extinction of organisms in a study area	0	0	1	1
	BB_Demographics, age, sex, size	Population demographics, including age, sex, and size	27	8	0	35
	BB_Fitness, survival, growth, condition, reproduction, mortality	Fitness, survival, growth, condition, reproduction, or mortality of organisms	34	38	6	78
	BB_Functional group, or species or trait composition	Grouping of organisms by functional or trait status, percentage composition	34	12	20	66
	BB_Genetics, mixing, metapopulation	Genetics and population mixing, including metapopulation dynamics	0	7	5	12
	BB_Habitat, critical habitat, or surrogates of such	Indices of habitat, area, suitability, and so on, for organisms	25	4	28	57
	BB_Internal composition nutrient abnormalities	Nutritional composition and makeup of organisms, including elemental stoichiometry. Includes levels of internal homeostasis, as well as morphological, genetic, or hormonal abnormalities caused by contaminants	0	3	0	3
	BB_Life history trait characteristics	Life history trait characteristics and their values, such as duration of spawning, fecundity, reproductive mode (note this category deals only with characteristics themselves and not the composition of the community.)	8	14	1	23
	BB_Presence, absence, occupancy, or detection	Organism presence/absence in an area (including pseudo-absence), occupancy, and detection probability	51	2	13	66

	BB_Richness, diversity, evenness, or IBI types of measures	Species richness, diversity, evenness, or indices-of-biotic-integrity metrics used to characterize one or more components of the biotic community	33	4	19	56
Connectivity & Fragmentation	CF_Basin area	Some aspect of area of river basin	8	0	1	9
	CF_Dendritic network and riverscape	Fragment length, dendritic connectivity index, barrier index, river distance between dams and projects	96	5	73	174
	CF_Fish passage	Mitigated fish passage, including presence of upstream or downstream passage or length of bypass	16	14	4	34
Geomorphology	GM_Catchment and basin attributes	Upland soil characteristics, topography, and landscape erodibility metrics that could influence soil erosion and wasting related and subsequent sedimentation related to hydropower development	15	5	2	22
	GM_Channel	Channel properties such as bankfull width, wetted width, bankfull discharge, channel slope, braided channel, channelization	56	18	18	91
	GM_Flooplain valley	Metrics related to channel confinement, entrenchment, migration, etc.	10	2	6	18
	GM_Sediment and substrate	Sediment and substrate properties such as substrate particle size, bedload, sediment entrainment or deposition, bedrock composition	31	25	14	70
Infrastructure & Design	ID_Dam attributes	Head, dam height, spill gate type, bar rack, and so on	97	2	5	104
	ID_Fish passage	Characteristics of fish passage structures such as slope, velocity, and discharge	9	0	2	11
	ID_Turbine	Turbine characteristics including forces in the turbine environment such as pressure, shear, cavitation, turbine type, turbine speed, blade strike	15	5	1	21

Land Cover	LC_Area impacted, project area	Project boundary area, area impacted by the project as whole, not related to reservoir inundation or land cover	41	0	2	43
	LC_Floodplain or riparian vegetation	Properties of floodplain or riparian vegetation such as riparian encroachment or floodplain area	1	0	0	1
	LC_Land cover class	Type of land cover, changes in land cover	13	19	4	36
	LC_Protected land	Spatial properties of protected lands including losses or increases	14	3	3	20
	LC_Reservoir inundation	Reservoir area, upland or floodplain inundation, biomass inundated/lost	20	2	0	22
Water Quantity	W1_Basin attributes	Attributes related to factors that influence hydrology (or were used in the context of hydrology), such as climate and precipitation	2	1	3	7
	W1_Diversion	Quantitative properties of diversions such as volume or discharge of diversion or water for other uses	6	1	1	8
	W1_Downstream discharge and hydrology	Measures that describe the magnitude, frequency, duration, periodicity, and timing of flows downstream of a hydropower facility, including changes to these characteristics	89	514	272	875
	W1_Groundwater	Groundwater characteristics	3	19	0	22
	W1_Reservoir hydrology	Reservoir hydrological characteristics such as residence time, reservoir fluctuation, reservoir surface area, or degree of regulation	61	16	8	85
	W1_Upstream regulation and inflow	Measures describing the magnitude, frequency, duration, periodicity, and timing of flows upstream of a hydropower facility, including changes to these characteristics	25	11	1	37
Water Quality	W2_Algae, primary productivity	Algal concentration including measures of primary productivity such as chlorophyll A or cyanotoxin.	25	7	2	33
	W2_Buffering capacity	Characteristics including pH, alkalinity	26	9	0	35

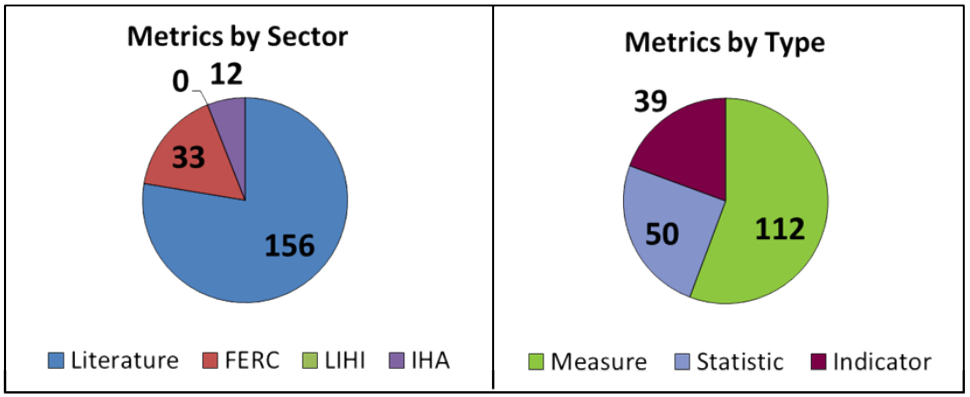
W2_Dissolved gasses	Concentration of non-greenhouse gases in water	9	0	0	9
W2_Dissolved oxygen	Dissolved oxygen in water	9	9	2	20
W2_Ecosystem function	Ecosystem vital rates and processes, including gross primary productivity, respiration, biochemical oxygen demand	5	7	1	13
W2_Gas emissions	Concentration and ebullution of water-origin greenhouse gases	12	17	1	30
W2_Nutrients	All non-rare elements essential to life: nitrogen, phosphorous, inorganic carbon, potassium, sulfur, and magnesium compounds (rare essential elements are included in "other elements")	99	42	2	143
W2_Organic material	Dissolved organic carbon and other organic non-pollutants	7	1	1	9
W2_Other elements	Elements and compounds that are not listed on the EPA Toxic and Priority Pollutants list	461	9	0	470
W2_Pollutants	Pollutants listed on the EPA Toxic and Priority Pollutants list that are not included in other EMH categories	69	0	7	71
W2_Solid transport, turbidity, and conductivity	Descriptions of dissolved and suspended solids in water such as turbidity, suspended or dissolved solids, conductance	53	13	4	70
W2_Temperature	Water temperature	33	18	4	60

3.1 GM_Geomorophology

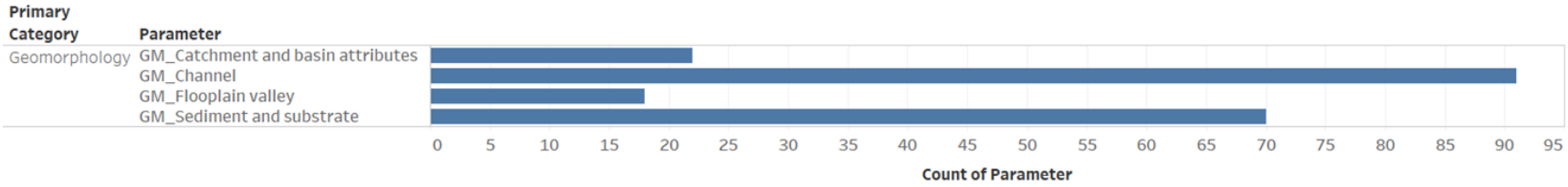
Geomorphology is the dynamic evolution of topographic and bathymetric features created within an ecosystem. Hydropower development can disrupt a river system's geomorphologic equilibrium through altered sediment and flow regimes. These changes have the potential to impact the availability and quality of habitats for plants and animals within the system.

GM Geomorphology

Sector	# of studies	# of metrics
IHA	4	12
LIHI	5	0
FERC	5	33
Peer-Reviewed Literature	247	156
Totals	261	201

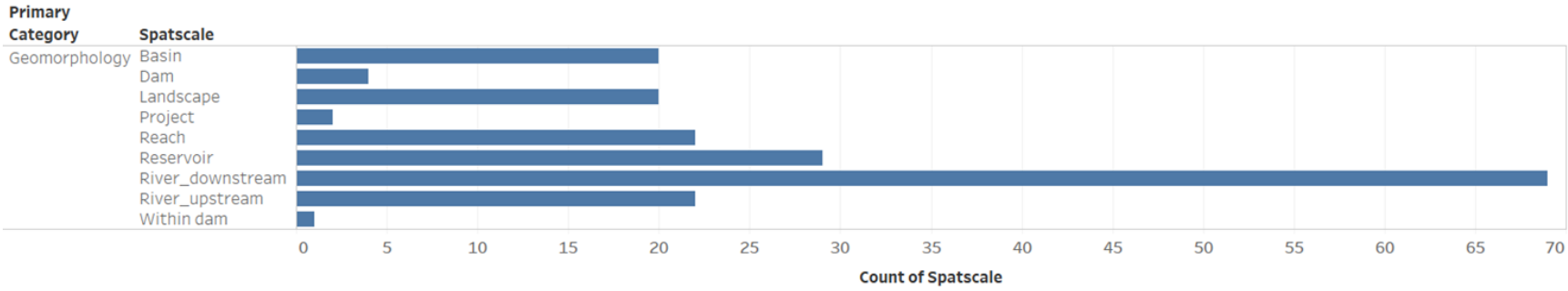


Geomorphology parameter frequency at study-level (extraction table)



Count of Parameter for each Parameter broken down by Primary Category. The view is filtered on Primary Category, which keeps Geomorphology.

Spatial scales for **geomorphology** represented at study-level (extraction table)



Count of Spatscale for each Spatscale broken down by Primary Category.

Frequencies based on EMH Catalog Contents as of January 31, 2017

3.1.1 GM_Catchment and basin attributes

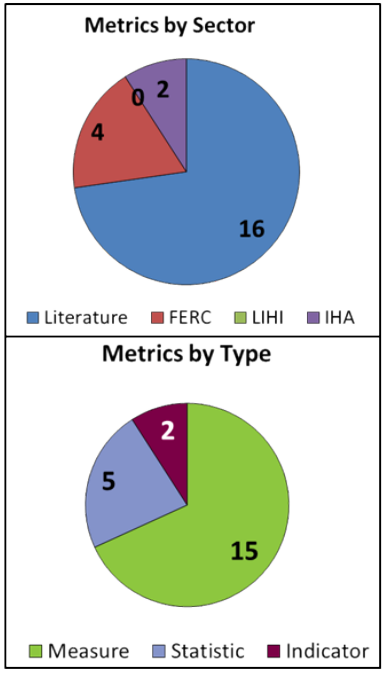
1

GM_Catchment and basin attributes

Upland soil characteristics, topography, and landscape erodibility metrics that could influence soil erosion and wasting related and subsequent sedimentation related to hydropower development

GM Geomorphology

Sector	studies	metrics
IHA	4	2
LIHI	5	0
FERC	5	4
Peer-Reviewed Literature	247	16
Totals	261	22



Metric Type	Metric Name
Measure	Basin area
Measure	Catchment size
Measure	Channel slope
Measure	Digital elevation model
Measure	Geology type
Measure	Local altitude
Measure	Slope
Measure	Soil type
Measure	Soils
Measure	Surface geology
Statistic	Catchment altitude-- average
Statistic	Matric suction
Statistic	Permeability function
Statistic	Soil-water characteristic curve
Statistic	Water content-- volumetric
Indicator	Baseline erosion and sedimentation
Indicator	Erosion study

Frequencies based on EMH Catalog Contents as of January 31, 2017

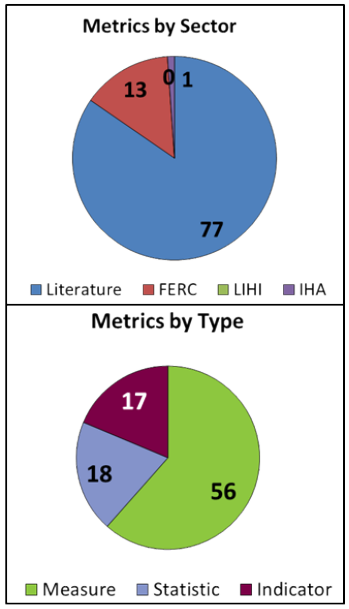
3.1.2 GM_Channel

GM Geomorphology

GM_Channel

Channel properties such as bankfull width, wetted width, bankfull discharge, channel slope, braided channel, channelization

Sector	studies	metrics
IHA	4	1
LIHI	5	0
FERC	5	13
Peer-Reviewed Literature	247	77
Totals	261	91



Metric Type	Metric Name
Measure	Bank slope
Measure	Bankfull cross sectional area
Measure	Bankfull depth
Measure	Bankfull width
Measure	Channel cross-section-- distance from left bank
Measure	Channel elevation
Measure	Channel elevation cross-section longitudinal
Measure	Channel gradient
Measure	Channel pattern
Measure	Channel soil type
Measure	Channel width
Measure	Channel width active
Measure	Elevation of sandbar above sea level
Measure	Engineered surface area
Measure	Erosion coastal
Measure	Flow velocity
Measure	High bar area
Measure	High-flow channel area
Measure	Island area
Measure	Low bar area
Measure	Low-flow channel area
Measure	Reach length
Measure	River slope
Measure	River type
Measure	River width
Measure	Sediment deposition
Measure	Water depth
Measure	Water depth-- regulated stream
Measure	Water depth--unregulated stream
Measure	Water velocity
Measure	Water velocity-- channel
Measure	Water veocity surface-- regulated stream

Metric Type	Metric Name
Measure	Water veocity surface-- unregulated stream
Measure	Wetted perimeter
Measure	Wetted width and depth
Measure	Width channel cross-section
Statistic	Channel width active
Statistic	Channel width active-- maximum
Statistic	Channel width active-- minimum
Statistic	GIS cells outside of threshold-- percent
Statistic	Pool, run, riffle-- percent
Statistic	Stream power
Statistic	Stream width-- average
Statistic	Water depth-- average
Statistic	Water velocity
Statistic	Water velocity-- average
Indicator	Bank erodability
Indicator	Bank erosion
Indicator	Bathymetric surveys
Indicator	Bed degradation
Indicator	Channel cross-section-- measurements
Indicator	Channel elevation change
Indicator	Channel elevation-- change
Indicator	Channel erosion
Indicator	Channel width active-- percent change
Indicator	Channelization presence
Indicator	Lateral migration
Indicator	Net land loss
Indicator	Rate land loss
Indicator	U-shaped cross section
Indicator	Width channel cross-section-- change

Frequencies based on EMH Catalog Contents as of January 31, 2017

3.1.3 GM_Floodplain valley

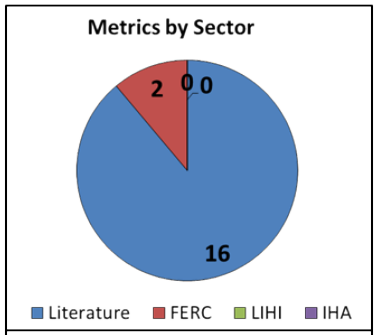
1

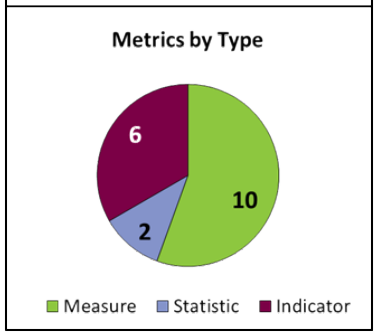
GM_Floodplain valley

Metrics related to channel confinement, entrenchment, migration, etc.

GM Geomorphology

Sector	studies	metrics
IHA	4	0
LIHI	5	0
FERC	5	2
Peer-Reviewed Literature	247	16
Totals	261	18





Metric Type	Metric Name
Measure	Floodplain active area
Measure	Floodplain characteristics
Measure	Floodplain extent
Measure	Floodplain inactive area
Measure	Shoreline length
Measure	Valley form
Measure	Valley slope
Statistic	Accumulated deformation landface
Statistic	Watershed erosion
Indicator	Impact factor
Indicator	Precipitation patterns for estimating sediment yield-- qualitative
Indicator	Ratio of factor of safety-- change
Indicator	Runoff patterns for estimating sediment yield-- qualitative
Indicator	Soil stratigraphy
Indicator	Upland erosion

Frequencies based on EMH Catalog Contents as of January 31, 2017

3.1.4 GM_Sediment and substrate

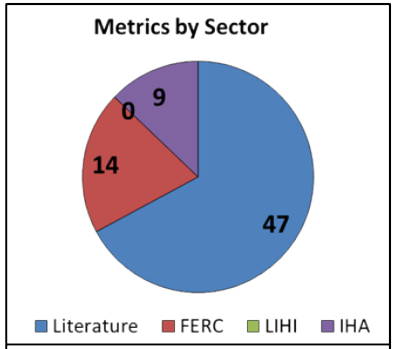
1

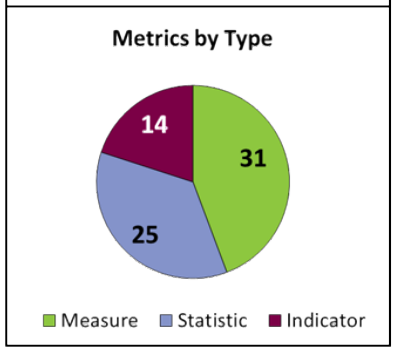
GM Geomorphology

GM_Sediment and substrate

Sediment and substrate properties such as substrate particle size, bedload, sediment entrainment or deposition, bedrock composition

Sector	studies	metrics
IHA	4	9
LIHI	5	0
FERC	5	14
Peer-Reviewed Literature	247	47
Totals	261	70





Metric Type	Metric Name
Measure	Bedload transport
Measure	Dry bulk density of sediment
Measure	Excavation volume
Measure	Gravel deposit area
Measure	Gravel deposit depth
Measure	Natural sediment
Measure	Particle size analysis
Measure	Periodic assessments of lake sedimentation
Measure	Reservoir sediment volume
Measure	Sediment export
Measure	Sediment grain size
Measure	Sediment inflow
Measure	Sediment layer depth and thickness
Measure	Sediment type
Measure	Specific degradation land
Measure	Substrate composition qualitative
Measure	Substrate size
Measure	Substrate type
Measure	Suspended sediment
Statistic	GIS cells with deposition-- percent
Statistic	GIS cells with scour-- percent
Statistic	Minerological analysis
Statistic	Modeling of erosion and sedimentation scenarios
Statistic	Reservoir sediment trapping
Statistic	Reservoir sediment yield
Statistic	Sediment grain size
Statistic	Sediment grain size-- cumulative frequency distribution
Statistic	Sediment grains below threshold-- percent
Statistic	Sediment inflow-- mean annual
Statistic	Sediment particle size-- distribution
Statistic	Sediment yield bathymetry

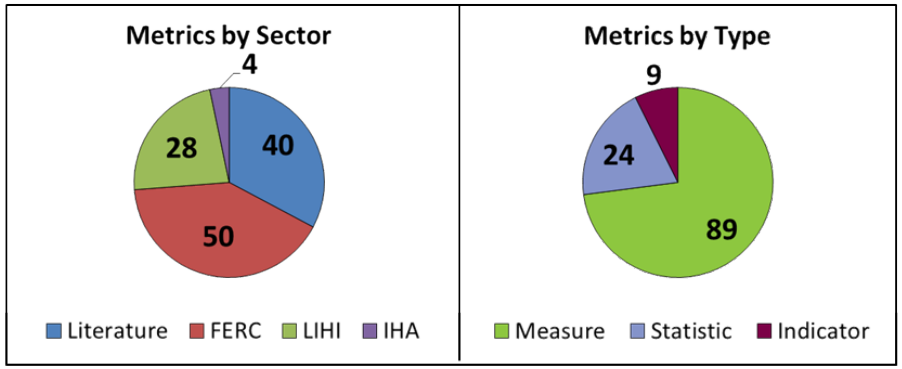
Metric Type	Metric Name
Statistic	Sedimentation-- mean annual
Statistic	Substrate coarseness regulated site
Statistic	Substrate coarseness unregulated site
Statistic	Substrate heterogeneity regulated site
Statistic	Substrate heterogeneity unregulated site
Statistic	Substrate particle size -- average
Statistic	Substrate particle size -- median
Statistic	Transect & sieve analysis of sediment
Indicator	Annual shoreline erosion inspections
Indicator	Bathymetric monitoring of reservoir
Indicator	Bedload transport
Indicator	Brune's design equations
Indicator	Erosion and subsequent sediment tranport
Indicator	Landslides and erosion
Indicator	Percent volume fraction of sediment < 8um in diameter
Indicator	Reservoir sediment trapping efficiency
Indicator	Sediment storage-- fine
Indicator	Sediment supply
Indicator	Sediment transport-- historic
Indicator	Suspended sediment transport

Frequencies based on EMH Catalog Contents as of January 31, 2017

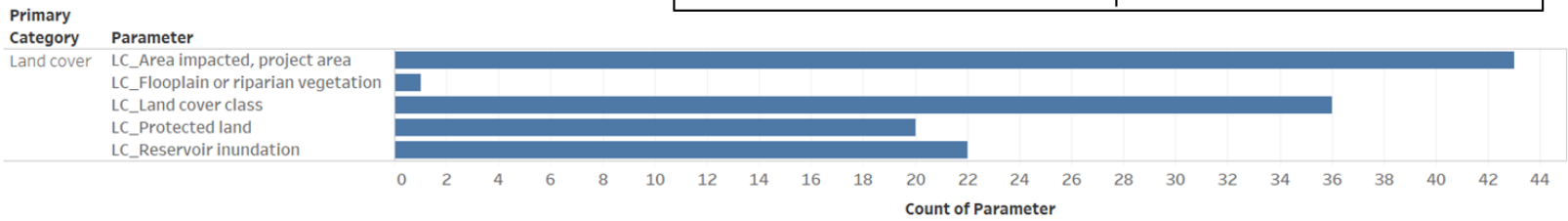
3.2 LC_Land Cover

Land cover type (the type of physical material on the Earth's surface) is an important measure of ecosystem health because it influences many other environmental properties— ranging from river and floodplain sedimentation rates to fragmentation of habitats and wildlife populations—at scales ranging from site to landscape. Changes in land cover type are an important component of a full description of ecosystem changes associated with hydropower development, such as increases in wetted surface resulting from reservoir formation, or fragmentation of the surrounding landscape due to the installation of supporting infrastructure (e.g., transmission lines, roads). Land cover characterization before and after hydropower development is an important component of understanding hydropower-affected ecosystems.

Sector	# of studies	# of metrics
IHA	4	4
LIHI	5	28
FERC	5	50
Peer-Reviewed Literature	247	40
Totals	261	122

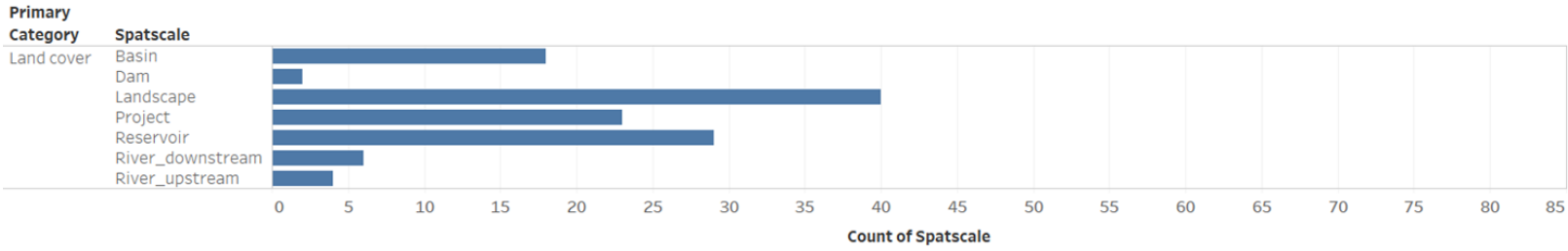


Land cover parameter frequency at study-level (extraction table)



Count of Parameter for each Parameter broken down by Primary Category. The view is filtered on Primary Category, which keeps Land cover.

Spatial scales for **land cover** represented at study-level (extraction table)



Count of Spatscale for each Spatscale broken down by Primary Category.

Frequencies based on EMH Catalog Contents as of January 31, 2017

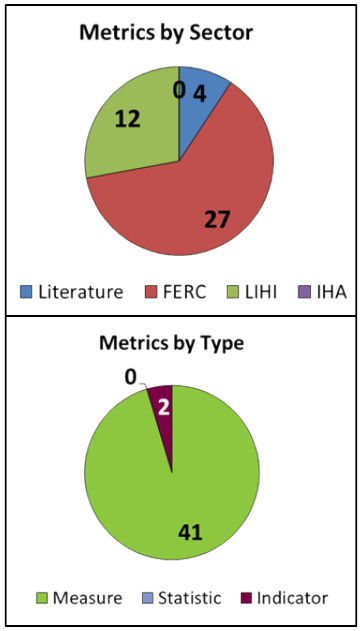
3.2.1 LC_Area impacted, project area

LC Land Cover

LC_Area impacted, project area

Project boundary area, area impacted by the project as whole, not related to reservoir inundation or land cover

Sector	studies	metrics
IHA	4	0
LIHI	5	12
FERC	5	27
Peer-Reviewed Literature	247	4
Totals	261	43



Metric Type	Metric Name
Measure	Bypass length
Measure	Byproduct disposal area
Measure	Dock permit/ access number
Measure	Facility footprint
Measure	Indian reservation presence
Measure	Length dewatered river
Measure	Non-reservoir facilities area
Measure	Patch area
Measure	Patch number
Measure	Potential effect area
Measure	Project boundary area
Measure	Project boundary area-- land
Measure	Project boundary area-- water
Measure	Recreational land area
Measure	Reservoir buffer zone acreage
Measure	Reservoir buffer zone area
Measure	Reservoir residences number
Measure	River length altered flow
Measure	Stream bed impact area
Measure	Tailwater length
Measure	Transmission line length
Measure	Transport distance of materials
Measure	Upland forest area impacted
Measure	Upland forest habitat area impacted
Measure	Wetland habitat area impacted
Indicator	Proximity index
Indicator	Wetland area impacted-- deviation

Frequencies based on EMH Catalog Contents as of January 31, 2017

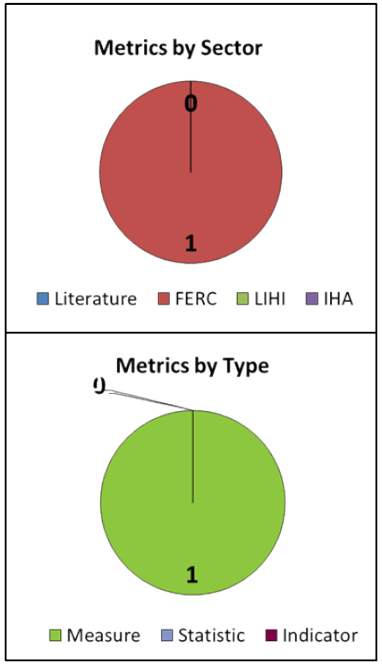
3.2.2 LC_Floodplain or riparian vegetation

LC_Floodplain or riparian vegetation

Properties of floodplain or riparian vegetation such as riparian encroachment or floodplain area

Sector	studies	metrics
IHA	4	0
LIHI	5	0
FERC	5	1
Peer-Reviewed Literature	247	0
Totals	261	1

Metric Type	Metric Name
Measure	River length of vegetation cover



Frequencies based on EMH Catalog Contents as of January 31, 2017

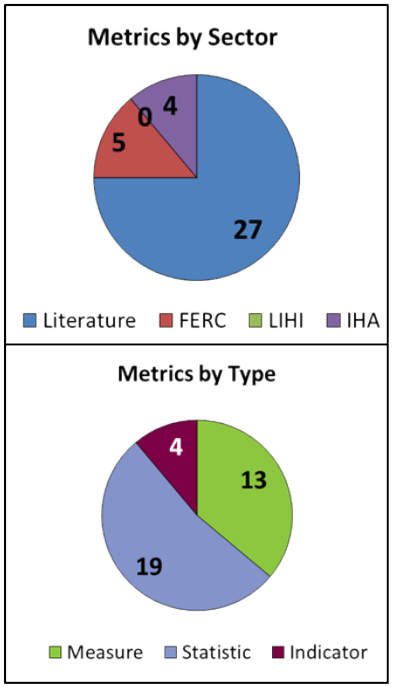
3.2.3 LC_Land cover class

LC Land Cover

LC_Land cover class

Type of land cover, changes in land cover

Sector	studies	metrics
IHA	4	4
LIHI	5	0
FERC	5	5
Peer-Reviewed Literature	247	27
Totals	261	36



Metric Type	Metric Name
Measure	Fluvial marsh area large regulated tributaries
Measure	Fluvial marsh area large unregulated tributaries
Measure	Forest area
Measure	Forest cover change
Measure	Ground cover
Measure	Lake area
Measure	Land development class
Measure	Land use
Measure	Open land area
Measure	Shoreline development length
Measure	Vegetation type
Measure	Wetland area
Statistic	Deforestation modeling
Statistic	Forest area-- percent
Statistic	Human population density
Statistic	Open land-- percent
Statistic	Reservoir area-- percent
Statistic	Shoreline developed-- percent
Statistic	Shoreline forested-- percent
Statistic	Watershed artificial land cover
Statistic	Watershed bare land cover
Statistic	Watershed coniferous land cover
Statistic	Watershed cultivated land cover
Statistic	Watershed deciduous land cover
Statistic	Watershed herbaceous land cover
Statistic	Watershed mixed forest land cover

Metric Type	Metric Name
Statistic	Watershed snow/ice land cover
Statistic	Watershed wetland land cover
Statistic	Watershed wetted land cover
Statistic	Wetland area-- percent
Indicator	Baseline land use
Indicator	Change in vegetation cover
Indicator	Cover
Indicator	Satellite imagery analysis of land use trends

Frequencies based on EMH Catalog Contents as of January 31, 2017

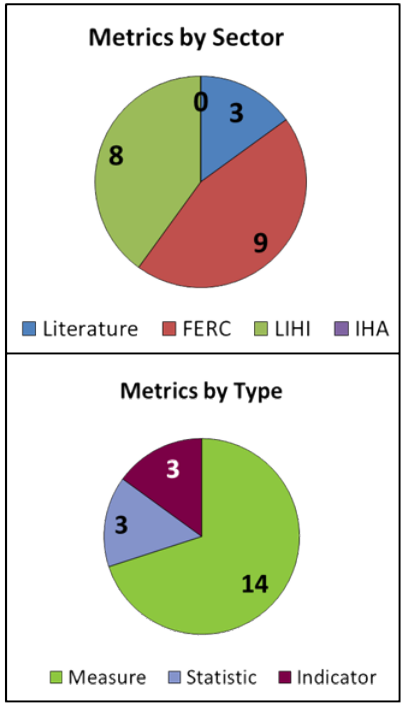
3.2.4 LC_Protected land

LC Land Cover

LC_Protected land

Spatial properties of protected lands including losses or increases

Sector	studies	metrics
IHA	4	0
LIHI	5	8
FERC	5	9
Peer-Reviewed Literature	247	3
Totals	261	20



type	MetricName
Measure	Conservation buffer zone presence
Measure	Conservation land area
Measure	Federal land area
Measure	Federal land presence
Measure	Federal/conservation land perimeter bounding
Measure	Length shoreline protected
Measure	Reservoir buffer zone area
Measure	Reservoir buffer zone width
Measure	Wildlife habitat lands
Statistic	Conservation land within reservoir buffer-- percent
Statistic	Shoreline length forested-- percent
Statistic	Shoreline protected/federal land-- percent
Indicator	Payment for ecosystem services related to forest management
Indicator	Value forest conservation for dam operator
Indicator	Value forest conservation for government

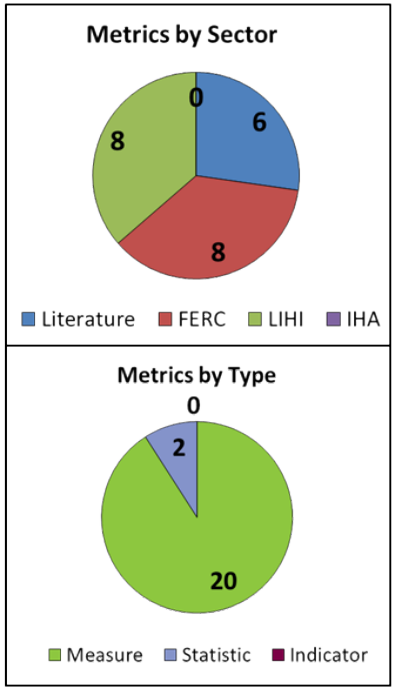
Frequencies based on EMH Catalog Contents as of January 31, 2017

3.2.5 LC_Reservoir inundation

LC_Reservoir inundation

Reservoir area, upland or floodplain inundation, biomass inundated/lost

Sector	studies	metrics
IHA	4	0
LIHI	5	8
FERC	5	8
Peer-Reviewed Literature	247	6
Totals	261	22



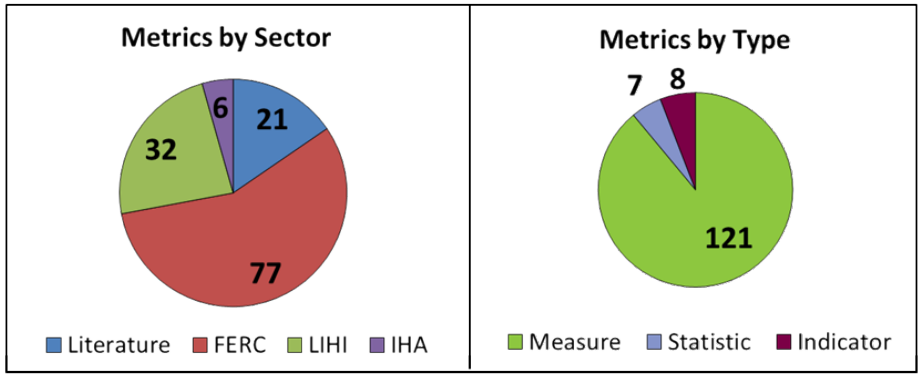
Metric Type	Metric Name
Measure	Island number
Measure	Island size
Measure	Normal full pond surface area
Measure	Reservoir capacity area
Measure	Reservoir inundation area
Measure	Reservoir inundation length
Measure	Reservoir length at average water level
Measure	Reservoir surface area
Measure	Shoreline length
Measure	Shoreline perimeter
Statistic	Reservoir length-- maximum
Statistic	Reservoir width-- maximum

Frequencies based on EMH Catalog Contents as of January 31, 2017

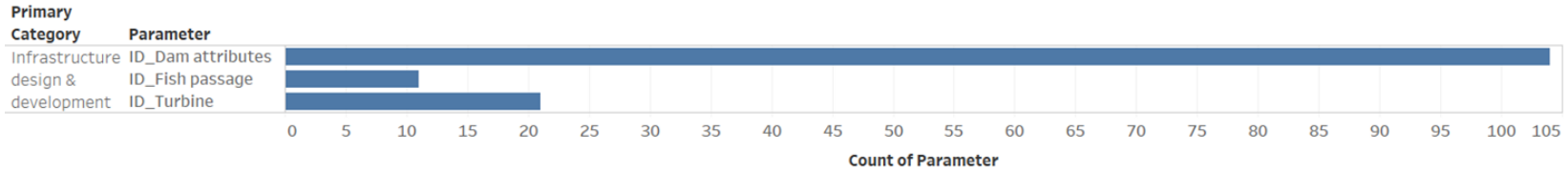
3.3 ID_Infrastructure and Design

Hydropower infrastructure involves the construction of structures in-stream (for impounding water and generating power) and on adjacent riparian and terrestrial lands (for transmitting power and accessing the site). The selection of hydropower equipment, associated infrastructure, and management practices can bear directly and indirectly on the other six categories through a variety of factors. These include increased land cover fragmentation due to transmission lines, exposure of animals and humans to electromagnetic fields, changes in the volume and timing of water releases, and the use of industrial lubricants needed to keep hydropower turbines working properly.

Sector	# of studies	# of metrics
IHA	4	6
LIHI	5	32
FERC	5	77
Peer-Reviewed Literature	247	21
Totals	261	136

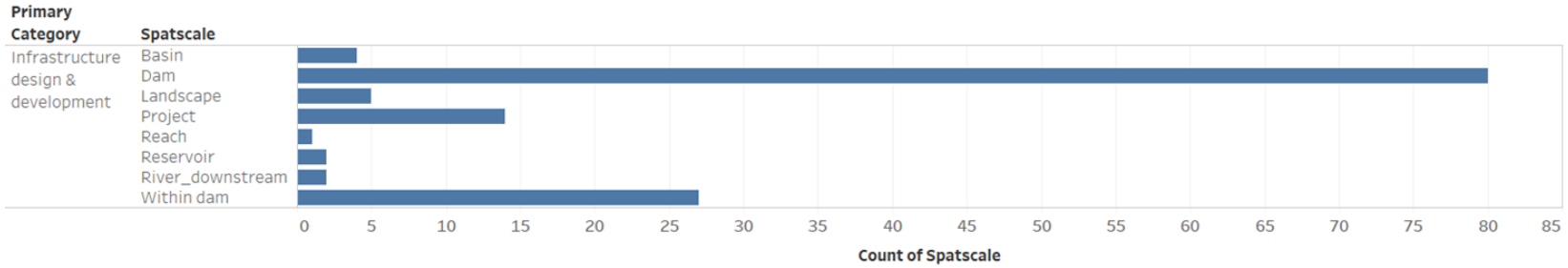


Infrastructure parameter frequency at study-level (extraction table)



Count of Parameter for each Parameter broken down by Primary Category. The view is filtered on Primary Category, which keeps Infrastructure design & development.

Spatial scales for **infrastructure** represented at study-level (extraction table)



Count of Spatscale for each Spatscale broken down by Primary Category.

Frequencies based on EMH Catalog Contents as of January 31, 2017

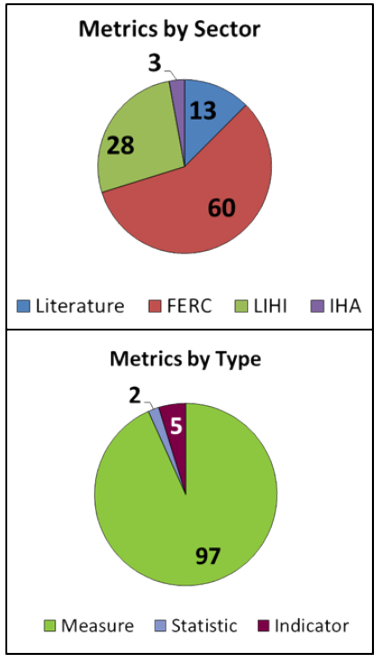
3.3.1 ID_Dam Attributes

ID Infrastructure and Design

ID_Dam attributes

Head, dam height, spill gate type, bar rack, and so on

Sector	studies	metrics
IHA	4	3
LIHI	5	28
FERC	5	60
Peer-Reviewed Literature	247	13
Totals	261	104



Metric Type	Metric Name
Measure	Complex number
Measure	Dam completion date
Measure	Dam height
Measure	Dam length
Measure	Dam number
Measure	Dam type
Measure	Discharge in flume
Measure	Discharge-- spillway
Measure	Energy production
Measure	Flashboard height
Measure	Flashboard presence
Measure	Flume length
Measure	Generation-- average annual
Measure	Head
Measure	Hydraulic head
Measure	Increased capacity
Measure	Increased hydraulic capacity
Measure	Inflow design flood
Measure	Installed capacity
Measure	Intake depth
Measure	Intake hydraulic capacity
Measure	Intake presence
Measure	Penstock length
Measure	Penstock number
Measure	Penstock/pipeline diameter
Measure	Penstock/pipeline length
Measure	Pipeline/tunnel/penstock length
Measure	Power generation
Measure	Powerhouse dimensions
Measure	Powerhouse integral
Measure	Powerhouse number
Measure	Reservoir age
Measure	Reservoir number
Measure	Reservoir outflow lower outlet
Measure	Reservoir outflow upper outlet

Metric Type	Metric Name
Measure	Sluiceway type
Measure	Spill gate dimensions
Measure	Spill gate number
Measure	Spill gate type
Measure	Spillway discharge capacity
Measure	Spillway length
Measure	Spillway presence
Measure	Track rack dimensions
Measure	Trash rack gate presence
Measure	Trashrack presence
Measure	Tunnel bypass length
Measure	Tunnel length
Measure	Tunnel number
Measure	Turbine-generator aeration
Measure	Turbine-generator unit number
Measure	Wall height
Measure	Water depth flume
Measure	Water release depth qualitative
Statistic	Open weir in advance of high flow
Statistic	Percent of time firm power demand met
Indicator	Dam-break envelope attenuation
Indicator	Increased capacity
Indicator	Increased generation
Indicator	Sediment-transport through desander
Indicator	Wet season flow

Frequencies based on EMH Catalog Contents as of January 31, 2017

3.3.2 ID_Fish passage

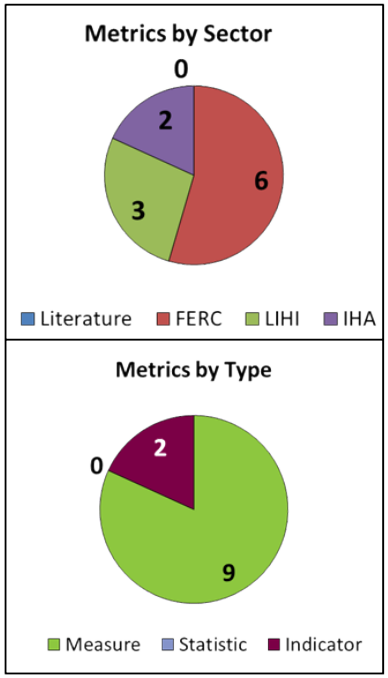
ID_Fish passage

Characteristics of fish passage structures such as slope, velocity, and discharge

ID Infrastructure and Design

Sector	studies	metrics
IHA	4	2
LIHI	5	3
FERC	5	6
Peer-Reviewed Literature	247	0
Totals	261	11

Metric Type	Metric Name
Measure	Design population
Measure	Design population diadromous fish
Measure	Fish lift height
Measure	Fish passage facility presence
Measure	Fishway biomass capacity
Measure	Trash rack spacing
Indicator	Fish passage and hatchery
Indicator	Threshold water velocity at intake



Frequencies based on EMH Catalog Contents as of January 31, 2017

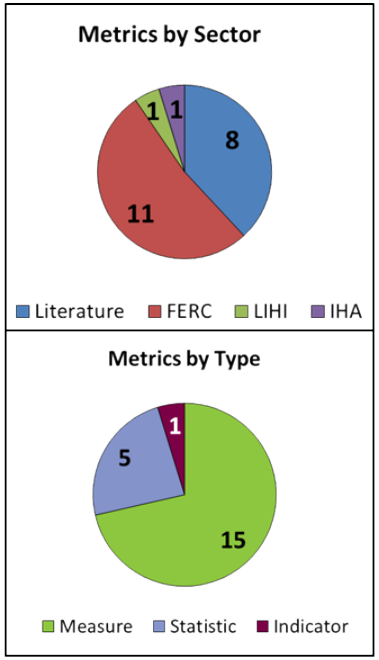
3.3.3 ID_Turbine

ID Infrastructure and Design

ID_Turbine

Turbine characteristics including forces in the turbine environment such as pressure, shear, cavitation, turbine type, turbine speed, blade strike

Sector	studies	metrics
IHA	4	1
LIHI	5	1
FERC	5	11
Peer-Reviewed Literature	247	8
Totals	261	21



type	MetricName
Measure	Approach velocity
Measure	Dam hydraulic capacity
Measure	Discharge-- turbine
Measure	Sweep velocity
Measure	Turbine hydraulic capacity
Measure	Turbine type
Measure	Turbine-generator aeration
Measure	Turbine-generator hydraulic capacity
Measure	Turbine-generator unit number
Statistic	Approach velocity-- average
Statistic	Percent of velocities >0.12 m/s
Statistic	Root mean square of approach velocity fluctuations
Statistic	Sweep velocity-- average
Statistic	Sweep velocity to approach velocity ratio
Indicator	Turbine abrasion

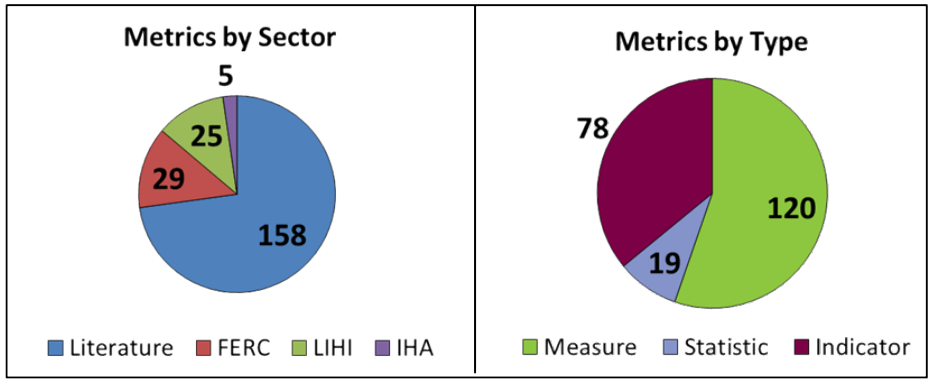
Frequencies based on EMH Catalog Contents as of January 31, 2017

3.4 CF_Connectivity and Fragmentation

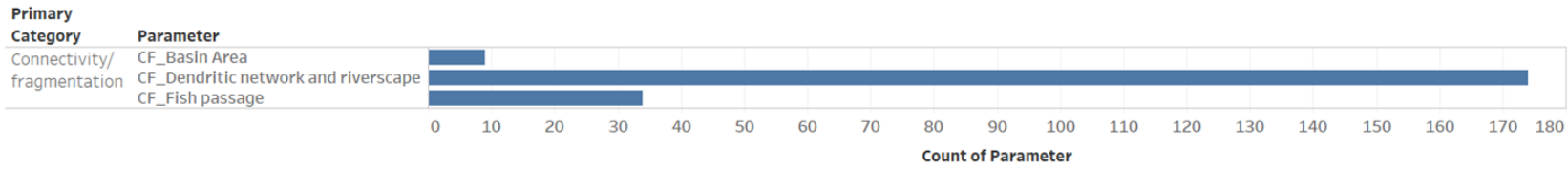
CF Connectivity and Fragmentation

Ecosystem connectivity (the degree to which a land cover type or ecosystem maintains continuity) and fragmentation (the degree to which an ecosystem or land cover type is disconnected) can affect the habitat quantity and quality for organisms in an ecosystem. Dams and their associated infrastructure can disrupt aquatic, riparian, and terrestrial connectivity, as well as groundwater connectivity, all of which can directly impact biota. Quantifying connectivity changes is therefore important for a full accounting of the environmental effects of hydropower.

Sector	# of studies	# of metrics
IHA	4	5
LIHI	5	25
FERC	5	29
Peer-Reviewed Literature	247	158
Totals	261	217

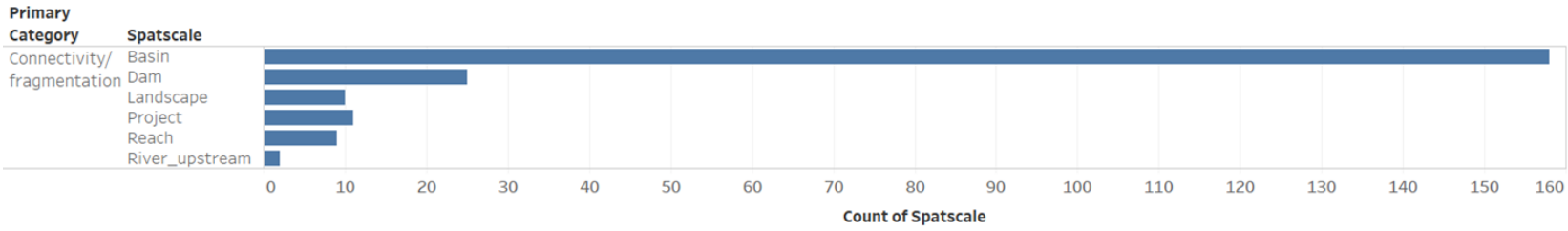


Connectivity parameter frequency at study-level (extraction table)



Count of Parameter for each Parameter broken down by Primary Category. The view is filtered on Primary Category, which keeps Connectivity/ fragmentation.

Spatial scales for **connectivity** represented at study-level (extraction table)



Count of Spatscale for each Spatscale broken down by Primary Category.

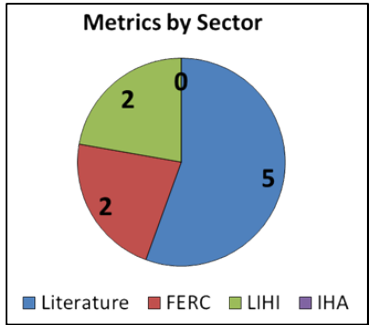
Frequencies based on EMH Catalog Contents as of January 31, 2017

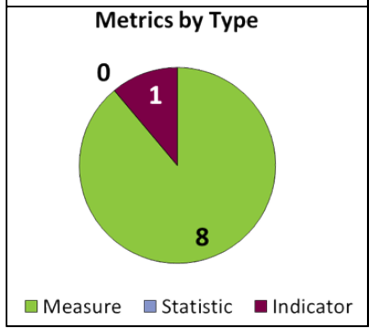
3.4.1 CF_Basin Area

CF_Basin area

Some aspect of area of river basin

Sector	studies	metrics
IHA	4	0
LIHI	5	2
FERC	5	2
Peer-Reviewed Literature	247	5
Totals	261	9





Metric Type	Metric Name
Measure	Annual flow coefficient of variation
Measure	Catchment area
Measure	Percent difference in pre-dam and post-dam annual flow coefficient of variation
Measure	River drainage area
Indicator	Percent difference between drainage area at flow-regulated and free-flowing fish survey pairs (calculated as [(reference) dam) /dam] · 100) a

Frequencies based on EMH Catalog Contents as of January 31, 2017

3.4.2 CF_Dendritic network and riverscape

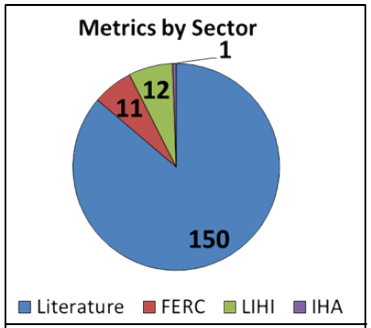
4

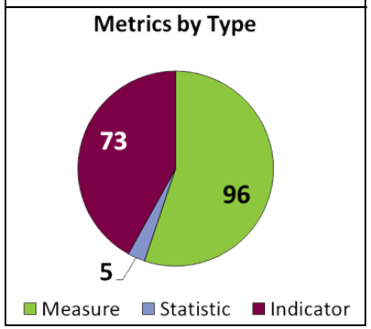
CF Connectivity and Fragmentation

CF_Dendritic network and riverscape

Fragment length, dendritic connectivity index, barrier index, river distance between dams and projects

Sector	studies	metrics
IHA	4	1
LIHI	5	12
FERC	5	11
Peer-Reviewed Literature	247	150
Totals	261	174





Metric Type	Metric Name
Measure	Distance from dam
Measure	Distance from estuary
Measure	Distance from mouth
Measure	Distance from river mouth
Measure	Distance pre-/ post-dam survey
Measure	Distance to source
Measure	Length 1st order upstream
Measure	Length 2nd order upstream
Measure	Length 3rd order upstream
Measure	Length 4th order upstream
Measure	Length river fragments
Measure	Length river network
Measure	Length river upstream
Measure	Linear distance between altered and unaltered sites
Measure	Number barriers
Measure	Number barriers downstream
Measure	Number barriers upstream
Measure	Number existing dams
Measure	Number facilities in basin
Measure	Number natural barriers
Measure	Number new dams
Measure	Number other dams
Measure	Number reservoir tributaries
Measure	Number river fragments
Measure	River distance between dams
Measure	River mile
Measure	Total river length
Measure	Total river water volume fragment

Metric Type	Metric Name
Measure	Total water volume entire river network
Measure	Upstream habitat length
Statistic	%total river length 1st order upstream
Statistic	%total river length 2nd order upstream
Statistic	%total river length 3rd order upstream
Statistic	Distance from confluence
Statistic	Maximum distance between any two components (gauge(s), fish survey and dam)
Indicator	Dam permeability by aquatic biota
Indicator	Degree of regulation
Indicator	Dendritic connectivity index
Indicator	Ensured tribuatary connectivity
Indicator	Percent difference drainage area between regulated and unregulated area
Indicator	River connectivity index
Indicator	River connectivity index-- disconnections
Indicator	River connectivity index-- fish

Frequencies based on EMH Catalog Contents as of January 31, 2017

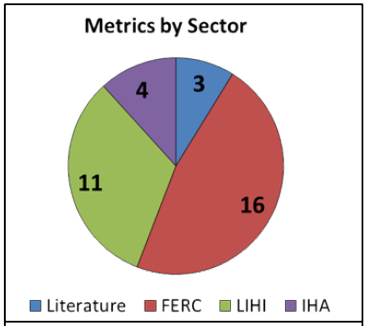
3.4.3 CF_Fish Passage

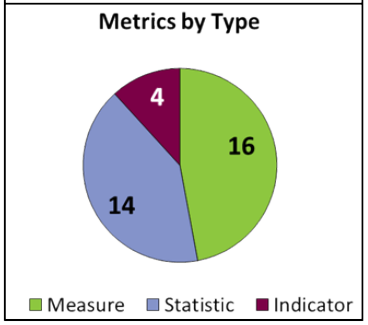
CF_Fish passage

Mitigated fish passage, including presence of upstream or downstream passage or length of bypass

CF Connectivity and Fragmentation

Sector	studies	metrics
IHA	4	4
LIHI	5	11
FERC	5	16
Peer-Reviewed Literature	247	3
Totals	261	34





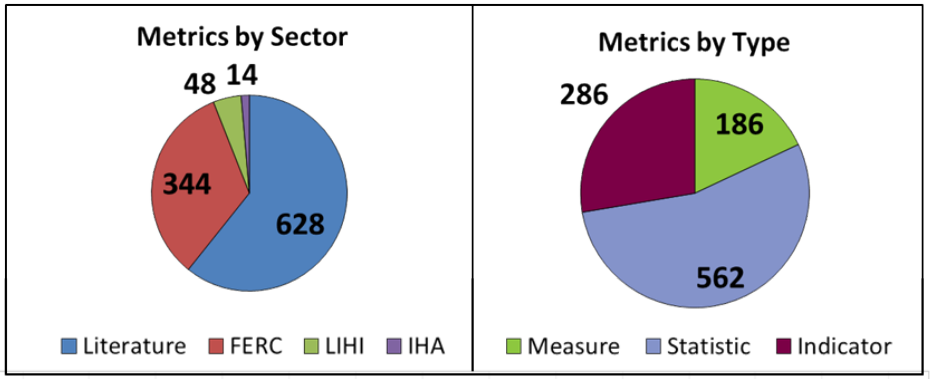
Metric Type	Metric Name
Measure	Entrainment/impingment presence
Measure	Fish passage abundance
Measure	Fish passage presence-- diadromous
Measure	Fish passage presence-- non-native
Measure	Fish passage presence-- potamodromous
Measure	Fish passage success-- count
Measure	Fishway biomass capacity
Measure	Number fish successfully passing dam
Measure	Number of elvers navigating the elver ladder
Measure	Turbine passage mortality
Statistic	Downstream passage survival-- minimum
Statistic	Fish passage abundance mean
Statistic	Fish passage abundance variation
Statistic	Fish passage richness
Statistic	Fish passage species composition
Statistic	Fish passage success
Statistic	Fish passage success-- average
Statistic	Fish passage survival
Statistic	Fishway genetic exchange
Statistic	Number of emigrants
Statistic	Passed fish-- maximum
Statistic	Survival rate fish passage
Statistic	Turbine passage survival
Indicator	Fish passage and restocking
Indicator	Fish passage efficiency
Indicator	Flow verification at fish ladder
Indicator	Rescued stranded fish

Frequencies based on EMH Catalog Contents as of January 31, 2017

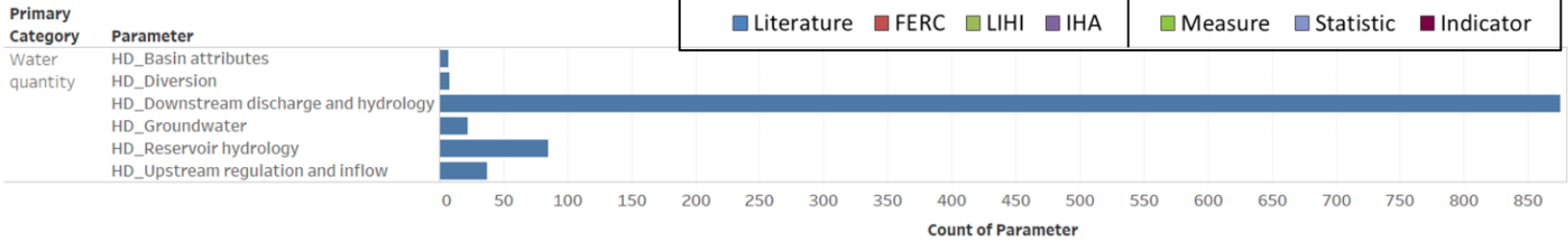
3.5 W1_Water Quantity

Water quantity refers to the amount of water found in-stream, in a reservoir, or in groundwater stores. It includes flow magnitude, duration, frequency, timing, and the rate of change of flows. Hydropower development can alter the quantity of water in several ways—through water storage in reservoirs, increased evaporation rates, changes in the availability of in-channel water downstream of a dam, and changes in the quantity of groundwater both upstream and downstream of dams. Because hydropower systems may be operated to fill a variety of purposes, changes to water quantity may occur at a variety of temporal scales ranging from diel to annual. Changes in water quantity can ultimately affect human and wildlife populations by altering water supplies for a variety of end uses (e.g., agricultural, drinking, municipal, industrial, recreational) and by changing habitat availability.

Sector	# of studies	# of metrics
IHA	4	14
LIHI	5	48
FERC	5	344
Peer-Reviewed Literature	247	628
Totals	261	1034

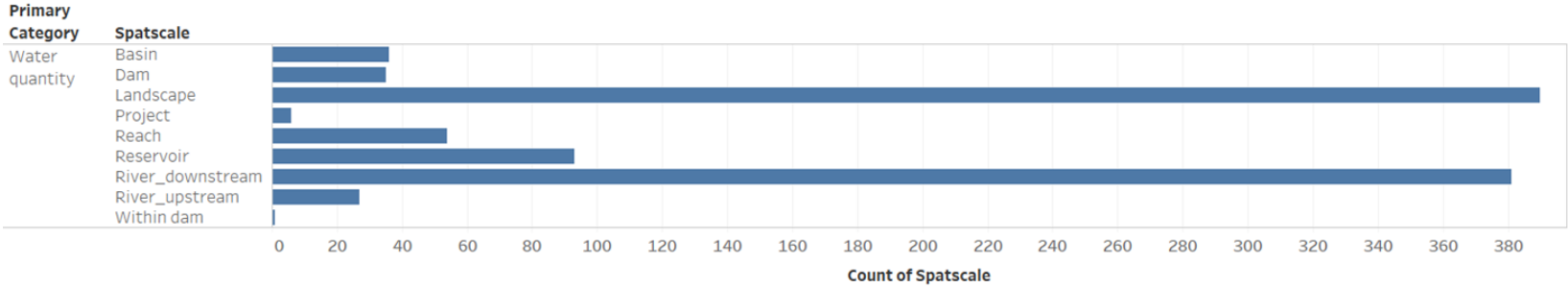


Water quantity parameter frequency at study-level (extraction table)



Count of Parameter for each Parameter broken down by Primary Category. The view is filtered on Primary Category, which keeps Water quantity.

Spatial scales for **water quantity** represented at study-level (extraction table)



Count of Spatscale for each Spatscale broken down by Primary Category.

Frequencies based on EMH Catalog Contents as of January 31, 2017

3.5.1 W1_Basin Attributes

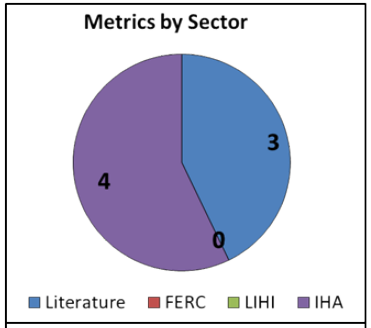
W1 Water Quantity

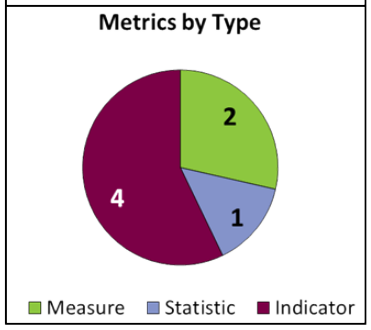
W1_Basin attributes

Attributes related to factors that influence hydrology (or were used in the context of hydrology), such as climate and precipitation

Sector	studies	metrics
IHA	4	4
LIHI	5	0
FERC	5	0
Peer-Reviewed Literature	247	3
Totals	261	7

Metric Type	Metric Name
Measure	Precipitation
Measure	Temperatur
Statistic	Air temperature-- average
Indicator	Baseline hydrology
Indicator	Cataract Gorge flows review
Indicator	Change in river morphology
Indicator	River behavior





Frequencies based on EMH Catalog Contents as of January 31, 2017

3.5.2 W1_Diversion

5

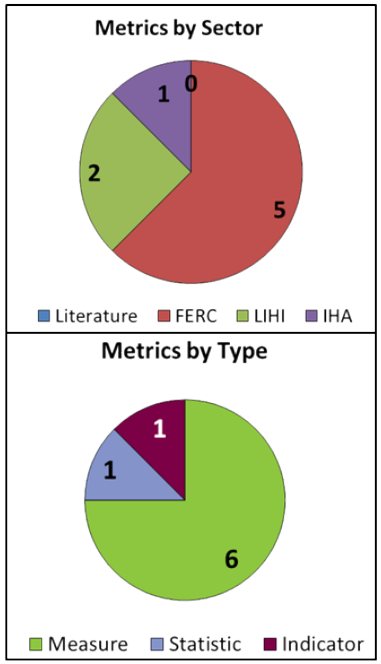
W1 Water Quantity

W1_Diversion

Quantitative properties of diversions such as volume or discharge of diversion or water for other uses

Sector	studies	metrics
IHA	4	1
LIHI	5	2
FERC	5	5
Peer-Reviewed Literature	247	0
Totals	261	8

Metric Type	Metric Name
Measure	Bypass reach presence
Measure	Consumptive withdrawal
Measure	Diversion presence
Statistic	Social water-use analysis
Indicator	Discharge-- flow reduction bypass

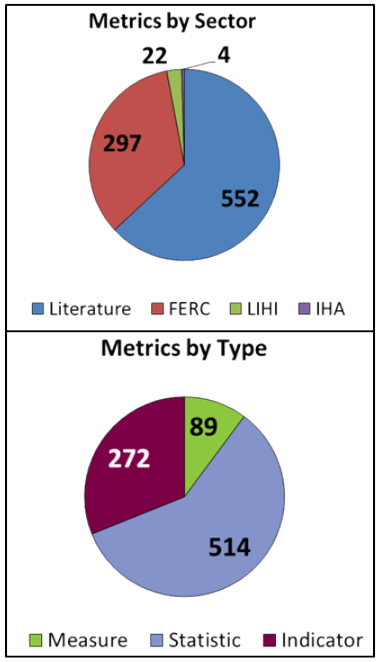


Frequencies based on EMH Catalog Contents as of January 31, 2017

3.5.3 W1_Downstream discharge and hydrology

W1 Water Quantity

Sector	studies	metrics
IHA	4	4
LIHI	5	22
FERC	5	297
Peer-Reviewed Literature	247	552
Totals	261	875



W1_Downstream discharge and hydrology

Measures that describe the magnitude, frequency, duration, periodicity, and timing of flows downstream of a hydropower facility, including changes to these characteristics

Metric Type	Metric Name
Measure	Bankful discharge
Measure	Boatable flow days
Measure	Capacity water flow regulation
Measure	Date water was first released from dam spillway
Measure	Discharge
Measure	Discharge-- attraction flow
Measure	Discharge-- channel creation flows
Measure	Discharge-- date high flow
Measure	Discharge-- discharge
Measure	Discharge-- frequency high flow
Measure	Discharge-- instantaneous outflow
Measure	Discharge-- Julian date maximum
Measure	Discharge-- magnitude high flow
Measure	Discharge-- minimum
Measure	Discharge-- minimum bypass
Measure	Discharge-- minimum seasonal
Measure	Discharge-- minimum target
Measure	Discharge of canal outflows
Measure	Discharge-- outflow
Measure	Discharge-- outflow fluctuation
Measure	Discharge-- regulated outflow
Measure	Discharge-- subdaily flow fluctuations
Measure	Discharge-- threshold seasonal low pulse
Measure	Discharge-- timing of greatest variation annual hydrograph
Measure	Discharge-- total hourly
Measure	Discharge-- variable minimum magnitude
Measure	Energy gradient elevation
Measure	Hydropeaking scheme
Measure	Mean flow
Measure	Mode of operation
Measure	Monthly flow
Measure	Number of days water released from dam spillway
Measure	potamodromous fish presence
Measure	Spill Discharge

Metric Type	Metric Name
Measure	Spill event magnitude
Measure	Stream channel water depth
Measure	Tailwater stage height
Measure	Total discharge
Measure	Total spill water volume-- seasonal
Measure	Volumetric flow-- daily
Measure	Water elevation downstream of dam
Statistic	Baseflow index
Statistic	Catastrophic flood discharge
Statistic	Change discharge-- standardized percent
Statistic	Dam seepage discharge
Statistic	Discharge -- coefficient of variation rate and frequency of change in conditions
Statistic	Discharge-- minimum annual 3 day maximum
Statistic	Discharge-- 1 day maximum
Statistic	Discharge-- 1 day minimum
Statistic	Discharge-- 3 day maximum
Statistic	Discharge-- 30 day maximum
Statistic	Discharge-- 30 day minimum
Statistic	Discharge-- 7 day maximum
Statistic	Discharge-- 90 day maximum
Statistic	Discharge-- annual
Statistic	Discharge-- annual 1 day maximum
Statistic	Discharge-- annual 1 day minimum
Statistic	Discharge-- annual 3 day maximum
Statistic	Discharge-- annual 3 day minimum
Statistic	Discharge-- annual 30 day maximum
Statistic	Discharge-- annual 30 day minimum
Statistic	Discharge-- annual 7 day maximum
Statistic	Discharge-- annual 7 day minimum
Statistic	Discharge-- annual 90 day maximum
Statistic	Discharge-- annual 90 day minimum
Statistic	Discharge-- annual coefficient of variation
Statistic	Discharge-- annual maximum
Statistic	Discharge-- average annual

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W1_Downstream discharge and hydrology

Measures that describe the magnitude, frequency, duration, periodicity, and timing of flows downstream of a hydropower facility, including changes to these characteristics

W1 Water Quantity

Metric Type	Metric Name
Statistic	Discharge-- average annual during incubation period
Statistic	Discharge-- average annual flow previous
Statistic	Discharge-- average April
Statistic	Discharge-- average August
Statistic	Discharge-- average daily
Statistic	Discharge-- average daily first year
Statistic	Discharge-- average daily gate discharge
Statistic	Discharge-- average daily turbine discharge
Statistic	Discharge-- average December
Statistic	Discharge-- average duration high pulses
Statistic	Discharge-- average duration low pulses
Statistic	Discharge-- average during rearing period
Statistic	Discharge-- average during spawning period
Statistic	Discharge-- average February
Statistic	Discharge-- average hourly
Statistic	Discharge-- average January
Statistic	Discharge-- average July
Statistic	Discharge-- average June
Statistic	Discharge-- average March
Statistic	Discharge-- average May
Statistic	Discharge-- average monthly
Statistic	Discharge-- average monthly dry year
Statistic	Discharge-- average monthly median precipitation year
Statistic	Discharge-- average November
Statistic	Discharge-- average October
Statistic	Discharge-- average percent total dam discharge released from spillway
Statistic	Discharge-- average score frequency and duration of high and low pulses
Statistic	Discharge-- average score magnitude and duration of annual extremes
Statistic	Discharge-- average score magnitude of monthly water conditions
Statistic	Discharge-- average score rate and frequency of change in conditions
Statistic	Discharge-- average score timing of annual
Statistic	Discharge-- average September
Statistic	Discharge-- baseflow index
Statistic	Discharge change from the previous day
Statistic	Discharge-- coefficient of variation frequency and duration high and low-flow pulses
Statistic	Discharge-- coefficient of variation magnitude and duration of annual extremes
Statistic	Discharge-- coefficient of variation magnitude of monthly water conditions
Statistic	Discharge-- daily
Statistic	Discharge-- daily annual maximum
Statistic	Discharge-- daily maximum
Statistic	Discharge-- days flow exceeds 25% first year
Statistic	Discharge-- days flow exceeds 25% incubation period records
Statistic	Discharge-- days flow exceeds 25% previous year flow
Statistic	Discharge-- days flow exceeds 75% first year
Statistic	Discharge-- days flow exceeds 75% incubation period records
Statistic	Discharge-- days flow exceeds 75% previous year flow
Statistic	Discharge-- days since high-flow
Statistic	Discharge-- days since low-flow
Statistic	Discharge-- days since reversal
Statistic	Discharge-- duration high-flow
Statistic	Discharge-- duration low-flow
Statistic	Discharge-- fall rate
Statistic	Discharge flux index
Statistic	Discharge-- frequency high-flow
Statistic	Discharge-- frequency high-flow pulse
Statistic	Discharge-- frequency low-flow
Statistic	Discharge-- frequency low-flow pulse
Statistic	Discharge-- frequency reversals
Statistic	Discharge-- frequency spill high flow
Statistic	Discharge-- frequency zero-flow days
Statistic	Discharge-- high pulse duration
Statistic	Discharge-- high-flow frequency
Statistic	Discharge-- Julian date annual maximum
Statistic	Discharge-- Julian date annual minimum
Statistic	Discharge-- Julian date maximum
Statistic	Discharge-- maximum
Statistic	Discharge-- maximum 10 day during rearing
Statistic	Discharge-- maximum 10 day during
Statistic	Discharge-- maximum annual
Statistic	Discharge-- maximum annual 1 day
Statistic	Discharge-- maximum annual 1 day
Statistic	Discharge-- maximum annual 1 day minimum
Statistic	Discharge-- maximum annual 3 day
Statistic	Discharge-- maximum annual 3 day
Statistic	Discharge-- maximum annual 3 day minimum
Statistic	Discharge-- maximum annual 30 day
Statistic	Discharge-- maximum annual 30 day
Statistic	Discharge-- maximum annual 30 day
Statistic	Discharge-- maximum annual 7 day
Statistic	Discharge-- maximum annual 7 day
Statistic	Discharge-- maximum annual 7 day minimum
Statistic	Discharge-- maximum annual 90 day
Statistic	Discharge-- maximum annual 90 day
Statistic	Discharge-- maximum annual 90 day
Statistic	Discharge-- maximum average April
Statistic	Discharge-- maximum average August
Statistic	Discharge-- maximum average December
Statistic	Discharge-- maximum average February
Statistic	Discharge-- maximum average January
Statistic	Discharge-- maximum average July

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W1_Downstream discharge and hydrology

Measures that describe the magnitude, frequency, duration, periodicity, and timing of flows downstream of a hydropower facility, including changes to these characteristics

W1 Water Quantity

Metric Type	Metric Name
Statistic	Discharge-- maximum average June
Statistic	Discharge-- maximum average March
Statistic	Discharge-- maximum average May
Statistic	Discharge-- maximum average November
Statistic	Discharge-- maximum average October
Statistic	Discharge-- maximum average September
Statistic	Discharge-- maximum baseflow index
Statistic	Discharge-- maximum daily average outflow
Statistic	Discharge-- maximum daily during
Statistic	Discharge-- maximum daily first year
Statistic	Discharge-- maximum daily flow previous
Statistic	Discharge-- maximum duration high-flow
Statistic	Discharge-- maximum duration low-flow
Statistic	Discharge-- maximum fall rate
Statistic	Discharge-- maximum frequency high-flow
Statistic	Discharge-- maximum frequency low-flow
Statistic	Discharge-- maximum generating
Statistic	Discharge-- maximum instantaneous
Statistic	Discharge-- maximum Julian date annual
Statistic	Discharge-- maximum Julian date annual
Statistic	Discharge-- maximum number of zero-flow
Statistic	Discharge-- maximum rise rate
Statistic	Discharge-- maximum/ minimum flow ratio
Statistic	Discharge-- maxumum
Statistic	Discharge-- median daily
Statistic	Discharge-- minimum 10 day during rearing
Statistic	Discharge-- minimum 10 day during
Statistic	Discharge-- minimum annual
Statistic	Discharge-- minimum annual 1 day
Statistic	Discharge-- minimum annual 1 day maximum
Statistic	Discharge-- minimum annual 1 day minimum
Statistic	Discharge-- minimum annual 3 day
Statistic	Discharge-- minimum annual 3 day minimum
Statistic	Discharge-- minimum annual 30 day
Statistic	Discharge-- minimum annual 30 day
Statistic	Discharge-- minimum annual 30 day
Statistic	Discharge-- minimum annual 7 day
Statistic	Discharge-- minimum annual 7 day maximum
Statistic	Discharge-- minimum annual 7 day minimum
Statistic	Discharge-- minimum annual 90 day
Statistic	Discharge-- minimum annual 90 day
Statistic	Discharge-- minimum annual 90 day
Statistic	Discharge-- minimum annual flow previous
Statistic	Discharge-- minimum average April
Statistic	Discharge-- minimum average August
Statistic	Discharge-- minimum average December
Statistic	Discharge-- minimum average February
Statistic	Discharge-- minimum average January
Statistic	Discharge-- minimum average July
Statistic	Discharge-- minimum average June
Statistic	Discharge-- minimum average March
Statistic	Discharge-- minimum average May
Statistic	Discharge-- minimum average November
Statistic	Discharge-- minimum average October
Statistic	Discharge-- minimum average September
Statistic	Discharge-- minimum baseflow index
Statistic	Discharge-- minimum daily during incubation
Statistic	Discharge-- minimum daily first year
Statistic	Discharge-- minimum duration high-flow
Statistic	Discharge-- minimum duration low-flow
Statistic	Discharge-- minimum fall rate
Statistic	Discharge-- minimum frequency high-flow
Statistic	Discharge-- minimum frequency low-flow
Statistic	Discharge-- minimum instantaneous
Statistic	Discharge-- minimum Julian date annual
Statistic	Discharge-- minimum Julian date annual
Statistic	Discharge-- minimum monthly
Statistic	Discharge-- minimum rise rate
Statistic	Discharge-- moderate flood
Statistic	Discharge-- monthly
Statistic	Discharge-- monthly baseflow duration
Statistic	Discharge-- monthly baseflow magnitude
Statistic	Discharge-- normal flood
Statistic	Discharge-- number days within 1 standard deviation of maximum
Statistic	Discharge-- percent days flow equalled or
Statistic	Discharge-- percent exceedance flow threshold values average monthly discharge
Statistic	Discharge-- percent exceedance flow threshold values maximum 1 day discharge
Statistic	Discharge-- percent exceedance flow threshold values maximum 3 day discharge
Statistic	Discharge-- percent exceedance flow threshold values maximum 30 day discharge
Statistic	Discharge-- percent exceedance flow threshold values maximum 7 day discharge
Statistic	Discharge-- percent exceedance flow threshold values maximum 90 day discharge
Statistic	Discharge-- percent exceedance flow threshold values minimum 1 day discharge
Statistic	Discharge-- percent exceedance flow threshold values minimum 3 day discharge
Statistic	Discharge-- percent exceedance flow threshold values minimum 30 day discharge
Statistic	Discharge-- percent exceedance flow threshold values minimum 7 day discharge
Statistic	Discharge-- percent exceedance flow threshold values minimum 90 day discharge
Statistic	Discharge-- percent exceedance flows
Statistic	Discharge-- Q7-10 flow
Statistic	Discharge-- range daily
Statistic	Discharge-- ratio average monthly to average

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W1_Downstream discharge and hydrology

Measures that describe the magnitude, frequency, duration, periodicity, and timing of flows downstream of a hydropower facility, including changes to these characteristics

W1 Water Quantity

Metric Type	Metric Name
Statistic	Discharge-- rise rate
Statistic	Discharge-- severe flood
Statistic	Discharge-- standard deviation average discharge during rearing period
Statistic	Discharge-- standard deviation average discharge during spawning period
Statistic	Discharge-- standard deviation minimum 10 d discharge during rearing period
Statistic	Discharge-- standard deviation minimum 10 d discharge during spawning period
Statistic	Discharge-- subdaily flow fluctuation
Statistic	Discharge-- timinimumg high flow events
Statistic	Discharge-- total daily freshwater inflow into
Statistic	Discharge-- total monthly freshwater inflow into estuary
Statistic	Discharge-- variability annual 1 day
Statistic	Discharge-- variability annual 1 day
Statistic	Discharge-- variability annual 3 day
Statistic	Discharge-- variability annual 3 day
Statistic	Discharge-- variability annual 30 day
Statistic	Discharge-- variability annual 30 day
Statistic	Discharge-- variability annual 7 day
Statistic	Discharge-- variability annual 7 day
Statistic	Discharge-- variability annual 90 day
Statistic	Discharge-- variability annual 90 day
Statistic	Discharge-- variability average April
Statistic	Discharge-- variability average August
Statistic	Discharge-- variability average December
Statistic	Discharge-- variability average February
Statistic	Discharge-- variability average January
Statistic	Discharge-- variability average July
Statistic	Discharge-- variability average June
Statistic	Discharge-- variability average March

Metric Type	Metric Name
Statistic	Discharge-- variability average May
Statistic	Discharge-- variability average November
Statistic	Discharge-- variability average October
Statistic	Discharge-- variability average September
Statistic	Discharge-- variability baseflow index
Statistic	Discharge-- variability duration high-flow
Statistic	Discharge-- variability duration low-flow
Statistic	Discharge-- variability fall rate
Statistic	Discharge-- variability frequency high-flow
Statistic	Discharge-- variability frequency low-flow
Statistic	Discharge-- variability high-flow frequency
Statistic	Discharge-- variability Julian date annual
Statistic	Discharge-- variability Julian date annual
Statistic	Discharge-- variability number of zero-flow
Statistic	Discharge-- variability rise rate
Statistic	Discharge wet year-- average monthly
Statistic	Discharge--frequency zero-flow days
Statistic	Down-ramp rate-- average
Statistic	Duration maximum variation annual
Statistic	Exceptional flood discharge
Statistic	Flow predictability
Statistic	Ramping rate
Statistic	Rate of channel dewatering
Statistic	Rate of channel dewatering - maximum
Statistic	Rate of channel dewatering - median
Statistic	Ratio of flow constancy to flow predictability
Statistic	Runoff
Statistic	Spill event frequency
Statistic	Spill event magnitude-- maximum
Statistic	Spill water volume-- average daily
Statistic	Tailwater elevation decrease
Statistic	Timing annual extremes Indicators of Hydrologic Alteration variables-- coefficient
Statistic	Total annual flow
Statistic	Up-ramp rate-- average

Metric Type	Metric Name
Statistic	Years between peak flows
Indicator	Degree of regulation
Indicator	Deviation baseflow index
Indicator	Deviation frequency low-flow
Indicator	Deviation high-flow frequency
Indicator	Discharge-- coefficient of variation percent change pre-/ post-dam annual baseflow
Indicator	Discharge-- deviation annual 1 day
Indicator	Discharge-- deviation annual 1 day
Indicator	Discharge-- deviation annual 1 day minimum
Indicator	Discharge-- deviation annual 3 day
Indicator	Discharge-- deviation annual 3 day minimum
Indicator	Discharge-- deviation annual 3 day minimum
Indicator	Discharge-- deviation annual 30 day
Indicator	Discharge-- deviation annual 30 day
Indicator	Discharge-- deviation annual 7 day
Indicator	Discharge-- deviation annual 7 day minimum
Indicator	Discharge-- deviation annual 90 day
Indicator	Discharge-- deviation annual 90 day
Indicator	Discharge-- deviation average April
Indicator	Discharge-- deviation average August
Indicator	Discharge-- deviation average December
Indicator	Discharge-- deviation average February
Indicator	Discharge-- deviation average January
Indicator	Discharge-- deviation average July
Indicator	Discharge-- deviation average June
Indicator	Discharge-- deviation average March
Indicator	Discharge-- deviation average May
Indicator	Discharge-- deviation average November
Indicator	Discharge-- deviation average October
Indicator	Discharge-- deviation average September
Indicator	Discharge-- deviation baseflow index
Indicator	Discharge-- deviation duration high-flow
Indicator	Discharge-- deviation duration low-flow
Indicator	Discharge-- deviation fall rate

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W1_Downstream discharge and hydrology

Measures that describe the magnitude, frequency, duration, periodicity, and timing of flows downstream of a hydropower facility, including changes to these characteristics

W1 Water Quantity

Metric Type	Metric Name
Indicator	Discharge-- deviation frequency low-flow
Indicator	Discharge-- deviation high-flow frequency
Indicator	Discharge-- deviation Julian date annual
Indicator	Discharge-- deviation Julian date annual
Indicator	Discharge-- deviation number of zero-flow
Indicator	Discharge-- deviation rise rate
Indicator	Discharge-- deviation annual 1 day maximum
Indicator	Discharge-- deviation annual 1 day minimum
Indicator	Discharge-- deviation annual 3 day maximum
Indicator	Discharge-- deviation annual 3 day minimum
Indicator	Discharge-- deviation annual 30 day
Indicator	Discharge-- deviation annual 30 day
Indicator	Discharge-- deviation annual 7 day maximum
Indicator	Discharge-- deviation annual 7 day minimum
Indicator	Discharge-- deviation annual 90 day
Indicator	Discharge-- deviation annual 90 day
Indicator	Discharge-- deviation average April
Indicator	Discharge-- deviation average August
Indicator	Discharge-- deviation average December
Indicator	Discharge-- deviation average February
Indicator	Discharge-- deviation average January
Indicator	Discharge-- deviation average July
Indicator	Discharge-- deviation average June
Indicator	Discharge-- deviation average March
Indicator	Discharge-- deviation average May
Indicator	Discharge-- deviation average November
Indicator	Discharge-- deviation average October
Indicator	Discharge-- deviation average September
Indicator	Discharge-- deviation baseflow index
Indicator	Discharge-- deviation duration high-flow
Indicator	Discharge-- deviation duration low-flow
Indicator	Discharge-- deviation fall rate
Indicator	Discharge-- deviation frequency high-flow
Indicator	Discharge-- deviation frequency low-flow
Indicator	Discharge-- deviation in high flow event
Indicator	Discharge-- deviation Julian date annual
Indicator	Discharge-- deviation Julian date annual
Indicator	Discharge-- deviation number of zero-flow
Indicator	Discharge-- deviation rise rate
Indicator	Discharge-- number days discharge exceeds thresholds
Indicator	Discharge-- percent change annual 1 day
Indicator	Discharge-- percent change annual 1 day
Indicator	Discharge-- percent change annual 3 day
Indicator	Discharge-- percent change annual 3 day
Indicator	Discharge-- percent change annual 30 day
Indicator	Discharge-- percent change annual 30 day
Indicator	Discharge-- percent change annual 7 day
Indicator	Discharge-- percent change annual 7 day
Indicator	Discharge-- percent change annual 90 day
Indicator	Discharge-- percent change annual 90 day
Indicator	Discharge-- percent change average April
Indicator	Discharge-- percent change average August
Indicator	Discharge-- percent change average
Indicator	Discharge-- percent change average February
Indicator	Discharge-- percent change average January
Indicator	Discharge-- percent change average July
Indicator	Discharge-- percent change average June
Indicator	Discharge-- percent change average March
Indicator	Discharge-- percent change average May
Indicator	Discharge-- percent change average
Indicator	Discharge-- percent change average October
Indicator	Discharge-- percent change average
Indicator	Discharge-- percent change baseflow index
Indicator	Discharge-- percent change duration high-
Indicator	Discharge-- percent change duration high-
Indicator	Discharge-- percent change duration low-flow
Indicator	Discharge-- percent change fall rate
Indicator	Discharge-- percent change frequency high-
Indicator	Discharge-- percent change frequency low-
Indicator	Discharge-- percent change high-flow
Indicator	Discharge-- percent change Julian date annual maximum
Indicator	Discharge-- percent change Julian date annual minimum
Indicator	Discharge-- percent change number of zero-
Indicator	Discharge-- percent change pre-/ post-dam annual baseflow
Indicator	Discharge-- percent change pre-/ post-dam annual predictability
Indicator	Discharge-- percent change pre-/ post-dam count high-flow pulse
Indicator	Discharge-- percent change pre-/ post-dam duration high-flow pulse
Indicator	Discharge-- percent change pre-/ post-dam ratio of flow constancy to flow predictability
Indicator	Discharge-- percent change rise rate
Indicator	Discharge-- percent months environmental flow requirement met
Indicator	Discharge-- rva target high annual 1 day
Indicator	Discharge-- rva target high annual 1 day
Indicator	Discharge-- rva target high annual 3 day
Indicator	Discharge-- rva target high annual 3 day
Indicator	Discharge-- rva target high annual 30 day
Indicator	Discharge-- rva target high annual 30 day
Indicator	Discharge-- rva target high annual 7 day
Indicator	Discharge-- rva target high annual 7 day
Indicator	Discharge-- rva target high annual 90 day
Indicator	Discharge-- rva target high annual 90 day
Indicator	Discharge-- rva target high average April
Indicator	Discharge-- rva target high average August

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W1_Downstream discharge and hydrology

Measures that describe the magnitude, frequency, duration, periodicity, and timing of flows downstream of a hydropower facility, including changes to these characteristics

W1 Water Quantity

Metric Type	Metric Name
Indicator	Discharge-- deviation frequency low-flow
Indicator	Discharge-- deviation high-flow frequency
Indicator	Discharge-- deviation Julian date annual
Indicator	Discharge-- deviation Julian date annual
Indicator	Discharge-- deviation number of zero-flow
Indicator	Discharge-- deviation rise rate
Indicator	Discharge-- deviation annual 1 day maximum
Indicator	Discharge-- deviation annual 1 day minimum
Indicator	Discharge-- deviation annual 3 day maximum
Indicator	Discharge-- deviation annual 3 day minimum
Indicator	Discharge-- deviation annual 30 day
Indicator	Discharge-- deviation annual 30 day
Indicator	Discharge-- deviation annual 7 day maximum
Indicator	Discharge-- deviation annual 7 day minimum
Indicator	Discharge-- deviation annual 90 day
Indicator	Discharge-- deviation annual 90 day
Indicator	Discharge-- deviation average April
Indicator	Discharge-- deviation average August
Indicator	Discharge-- deviation average December
Indicator	Discharge-- deviation average February
Indicator	Discharge-- deviation average January
Indicator	Discharge-- deviation average July
Indicator	Discharge-- deviation average June
Indicator	Discharge-- deviation average March
Indicator	Discharge-- deviation average May
Indicator	Discharge-- deviation average November
Indicator	Discharge-- deviation average October
Indicator	Discharge-- deviation average September
Indicator	Discharge-- deviation baseflow index
Indicator	Discharge-- deviation duration high-flow
Indicator	Discharge-- deviation duration low-flow
Indicator	Discharge-- deviation fall rate
Indicator	Discharge-- deviation frequency high-flow
Indicator	Discharge-- deviation frequency low-flow
Indicator	Discharge-- deviation in high flow event
Indicator	Discharge-- deviation Julian date annual
Indicator	Discharge-- deviation Julian date annual
Indicator	Discharge-- deviation number of zero-flow
Indicator	Discharge-- deviation rise rate
Indicator	Discharge-- number days discharge exceeds thresholds
Indicator	Discharge-- percent change annual 1 day
Indicator	Discharge-- percent change annual 1 day
Indicator	Discharge-- percent change annual 3 day
Indicator	Discharge-- percent change annual 3 day
Indicator	Discharge-- percent change annual 30 day
Indicator	Discharge-- percent change annual 30 day
Indicator	Discharge-- percent change annual 7 day
Indicator	Discharge-- percent change annual 7 day
Indicator	Discharge-- percent change annual 90 day
Indicator	Discharge-- percent change annual 90 day
Indicator	Discharge-- percent change average April
Indicator	Discharge-- percent change average August
Indicator	Discharge-- percent change average
Indicator	Discharge-- percent change average February
Indicator	Discharge-- percent change average January
Indicator	Discharge-- percent change average July
Indicator	Discharge-- percent change average June
Indicator	Discharge-- percent change average March
Indicator	Discharge-- percent change average May
Indicator	Discharge-- percent change average
Indicator	Discharge-- percent change average October
Indicator	Discharge-- percent change average
Indicator	Discharge-- percent change baseflow index
Indicator	Discharge-- percent change duration high-
Indicator	Discharge-- percent change duration high-
Indicator	Discharge-- percent change duration low-flow
Indicator	Discharge-- percent change fall rate
Indicator	Discharge-- percent change frequency high-
Indicator	Discharge-- percent change frequency low-
Indicator	Discharge-- percent change high-flow
Indicator	Discharge-- percent change Julian date annual maximum
Indicator	Discharge-- percent change Julian date annual minimum
Indicator	Discharge-- percent change number of zero-
Indicator	Discharge-- percent change pre-/ post-dam annual baseflow
Indicator	Discharge-- percent change pre-/ post-dam annual predictability
Indicator	Discharge-- percent change pre-/ post-dam count high-flow pulse
Indicator	Discharge-- percent change pre-/ post-dam duration high-flow pulse
Indicator	Discharge-- percent change pre-/ post-dam ratio of flow constancy to flow predictability
Indicator	Discharge-- percent change rise rate
Indicator	Discharge-- percent months environmental flow requirement met
Indicator	Discharge-- rva target high annual 1 day
Indicator	Discharge-- rva target high annual 1 day
Indicator	Discharge-- rva target high annual 3 day
Indicator	Discharge-- rva target high annual 3 day
Indicator	Discharge-- rva target high annual 30 day
Indicator	Discharge-- rva target high annual 30 day
Indicator	Discharge-- rva target high annual 7 day
Indicator	Discharge-- rva target high annual 7 day
Indicator	Discharge-- rva target high annual 90 day
Indicator	Discharge-- rva target high annual 90 day
Indicator	Discharge-- rva target high average April
Indicator	Discharge-- rva target high average August

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W1 Water Quantity

W1_Downstream discharge and hydrology

Measures that describe the magnitude, frequency, duration, periodicity, and timing of flows downstream of a hydropower facility, including changes to these characteristics

Metric Type	Metric Name
Indicator	Discharge-- rva target high average December
Indicator	Discharge-- rva target high average February
Indicator	Discharge-- rva target high average January
Indicator	Discharge-- rva target high average July
Indicator	Discharge-- rva target high average June
Indicator	Discharge-- rva target high average March
Indicator	Discharge-- rva target high average May
Indicator	Discharge-- rva target high average November
Indicator	Discharge-- rva target high average October
Indicator	Discharge-- rva target high average
Indicator	Discharge-- rva target high baseflow index
Indicator	Discharge-- rva target high duration high-
Indicator	Discharge-- rva target high duration low-flow
Indicator	Discharge-- rva target high fall rate
Indicator	Discharge-- rva target high frequency high-
Indicator	Discharge-- rva target high frequency low-
Indicator	Discharge-- rva target high Julian date annual maximum
Indicator	Discharge-- rva target high Julian date annual minimum
Indicator	Discharge-- rva target high number of zero-
Indicator	Discharge-- rva target high rise rate
Indicator	Discharge-- rva target low annual 1 day
Indicator	Discharge-- rva target low annual 1 day
Indicator	Discharge-- rva target low annual 3 day
Indicator	Discharge-- rva target low annual 3 day
Indicator	Discharge-- rva target low annual 30 day
Indicator	Discharge-- rva target low annual 30 day
Indicator	Discharge-- rva target low annual 7 day
Indicator	Discharge-- rva target low annual 7 day
Indicator	Discharge-- rva target low annual 90 day
Indicator	Discharge-- rva target low annual 90 day
Indicator	Discharge-- rva target low average April
Indicator	Discharge-- rva target low average August
Indicator	Discharge-- rva target low average December

Metric Type	Metric Name
Indicator	Discharge-- rva target low average February
Indicator	Discharge-- rva target low average January
Indicator	Discharge-- rva target low average July
Indicator	Discharge-- rva target low average June
Indicator	Discharge-- rva target low average March
Indicator	Discharge-- rva target low average May
Indicator	Discharge-- rva target low average November
Indicator	Discharge-- rva target low average October
Indicator	Discharge-- rva target low average September
Indicator	Discharge-- rva target low baseflow index
Indicator	Discharge-- rva target low duration high-flow
Indicator	Discharge-- rva target low duration low-flow
Indicator	Discharge-- rva target low fall rate
Indicator	Discharge-- rva target low frequency high-
Indicator	Discharge-- rva target low frequency low-flow
Indicator	Discharge-- rva target low Julian date annual maximum
Indicator	Discharge-- rva target low Julian date annual minimum
Indicator	Discharge-- rva target low number of zero-
Indicator	Discharge-- rva target low rise rate
Indicator	Dry season minimum flow
Indicator	Dundee hydrological regime assessment
Indicator	General release monitoring
Indicator	Maximum distance between points
Indicator	Studies of risks of flow allocation and variation on aquatic biota
Indicator	Tailwater elevation fluctuation

3.5.4 W1_Groundwater

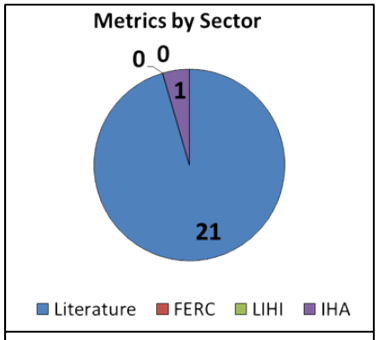
5

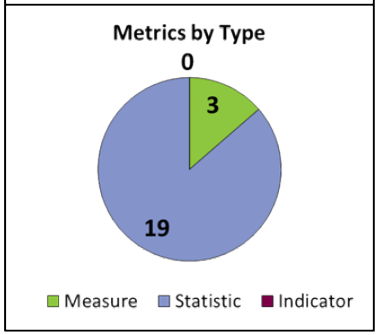
W1_Groundwater

Groundwater characteristics

W1 Water Quantity

Sector	studies	metrics
IHA	4	1
LIHI	5	0
FERC	5	0
Peer-Reviewed Literature	247	21
Totals	261	22





Metric Type	Metric Name
Measure	Groundwater discharge
Measure	Groundwater elevation
Measure	Groundwater storage
Statistic	Groundwater elevation-- average post-dam
Statistic	Groundwater elevation-- average pre-dam dry year
Statistic	Groundwater elevation-- average standard devation pre-dam dry year
Statistic	Groundwater elevation-- average standard deviation post-dam
Statistic	Groundwater elevation-- average standard deviation pre-dam dry year
Statistic	Groundwater elevation-- skewness post-dam
Statistic	Groundwater elevation-- skewness pre-dam
Statistic	Groundwater elevation-- skewness pre-dam dry year
Statistic	Groundwater elevation-- standard deviation of standard deviations post-dam
Statistic	Groundwater elevation-- standard deviation of standard deviations pre-dam
Statistic	Groundwater elevation-- standard deviation of standard deviations pre-dam dry year
Statistic	Groundwater elevation-- standard deviation post-dam
Statistic	Groundwater elevation-- standard deviation pre-dam
Statistic	Groundwater elevation-- standard deviation pre-dam dry year
Statistic	Groundwater runoff contributions
Statistic	Grounwater elevation-- skewness of standard deviations post-dam
Statistic	Grounwater elevation-- skewness of standard deviations pre-dam
Statistic	Grounwater elevation-- skewness of standard deviations pre-dam dry year

Frequencies based on EMH Catalog Contents as of January 31, 2017

3.5.5 W1_Reservoir hydrology

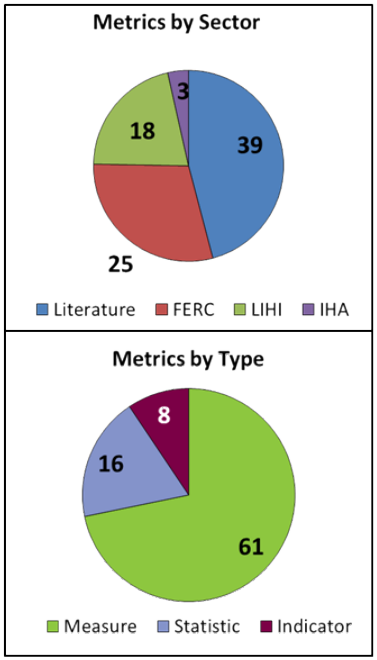
5

W1 Water Quantity

W1_Reservoir hydrology

Reservoir hydrological characteristics such as residence time, reservoir fluctuation, reservoir surface area, or degree of regulation

Sector	studies	metrics
IHA	4	3
LIHI	5	18
FERC	5	25
Peer-Reviewed Literature	247	39
Totals	261	85



Metric Type	Metric Name
Measure	Active reservoir storage
Measure	Dead reservoir storage
Measure	Detailed water level measurements
Measure	Headwater elevations-- daily
Measure	Hydraulic residence time
Measure	Hydraulic residence time-- minimum
Measure	Impounded water volume
Measure	Impoundment hydrology
Measure	Inundation volume-- average
Measure	Number reservoir tributaries
Measure	Reservoir drawdown-- seasonal
Measure	Reservoir elevation
Measure	Reservoir elevation-- daily
Measure	Reservoir elevation full pool
Measure	Reservoir elevation-- hourly
Measure	Reservoir fill timing
Measure	Reservoir inflow
Measure	Reservoir precipitation minimum evaporation
Measure	Reservoir storage
Measure	Reservoir storage-- maximum
Measure	Reservoir surface area
Measure	Reservoir surface evaporation
Measure	Reservoir use class
Measure	Reservoir volume
Measure	Reservoir water depth
Measure	Stream water depth
Measure	Useable reservoir storage volume

Metric Type	Metric Name
Measure	Water column dispersive transport
Measure	Water depth
Measure	Water depth reservoir
Measure	Water depth reservoir-- maximum
Statistic	Discharge-- 25th percentile average monthly flow
Statistic	Discharge-- percent useable reservoir storage volume
Statistic	Gauge height
Statistic	Hydraulic residence time-- average
Statistic	Hydraulic residence time-- maximum
Statistic	Net evaporation depth-- average monthly
Statistic	Normal daily reservoir drawdown
Statistic	Reservoir drawdown-- maximum
Statistic	Reservoir elevation-- average daily fluctuation
Statistic	Reservoir elevation-- average hourly
Statistic	Reservoir elevation fluctuation-- maximum
Statistic	Water depth-- average
Statistic	Water depth-- maximum
Statistic	Water depth reservoir-- average
Indicator	Continuous monitoring of water levels & flow
Indicator	Reservoir elevation fluctuation
Indicator	Reservoir level

Frequencies based on EMH Catalog Contents as of January 31, 2017

3.5.6 W1_Upstream regulation and inflow

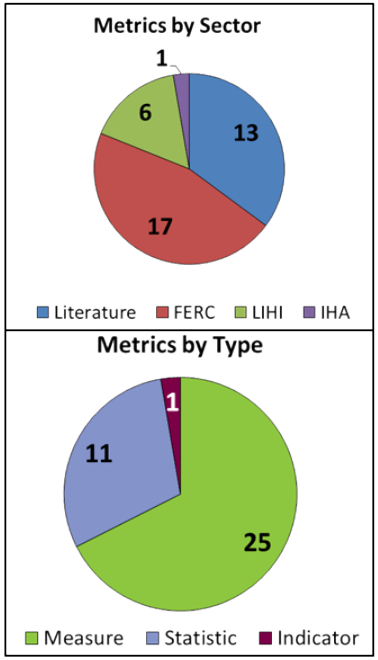
5

W1_Upstream regulation and inflow

Measures describing the magnitude, frequency, duration, periodicity, and timing of flows upstream of a hydropower facility, including changes to these characteristics

W1 Water Quantity

Sector	studies	metrics
IHA	4	1
LIHI	5	6
FERC	5	17
Peer-Reviewed Literature	247	13
Totals	261	37



Metric Type	Metric Name
Measure	Count upstream dams
Measure	Discharge-- average daily inflow
Measure	Discharge-- inflow
Measure	Discharge-- instantaneous inflow
Measure	Discharge-- median inflow
Measure	Discharge-- net inflow
Measure	Discharge of small tributary inflows
Measure	Discharge-- regulated inflow
Measure	Discharge-- reservoir inflow
Measure	Discharge-- river inflow
Measure	Discharge-- unregulated inflow
Measure	Discharge-- water balance estimated
Measure	Distance upstream dams
Measure	Number upstream dams
Measure	Precipitation
Measure	Precipitation falling directly into the reservoir
Measure	Reservoir inflow
Measure	Upstream area regulated
Measure	Water use in region
Statistic	Air temperature-- average July
Statistic	Air temperature-- difference average January and July
Statistic	Discharge-- average tributary inflow
Statistic	Discharge-- average unregulated inflow
Statistic	Discharge-- median daily inflow

Metric Type	Metric Name
Statistic	Discharge-- percent inflow to mainstem
Statistic	Discharge-- percent of inflow from upstream facility
Statistic	Discharge-- percent upstream area regulated
Statistic	Drainage area between facilities
Statistic	Precipitation-- average annual in catchment
Statistic	Rainfall-- average annual
Indicator	Flow regime of upper Isar

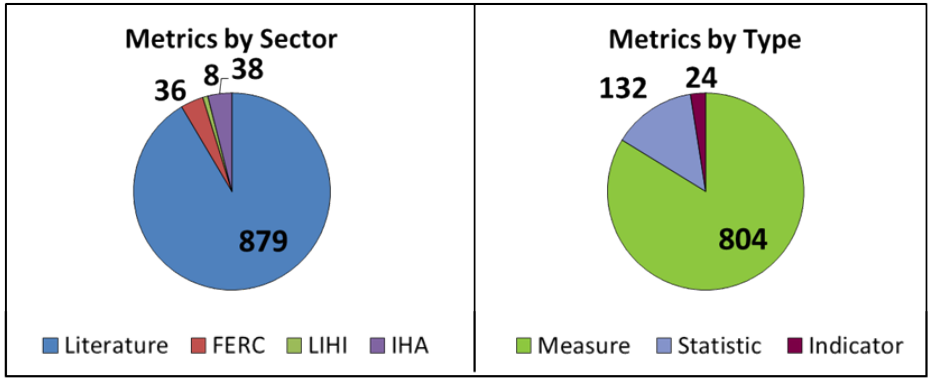
Frequencies based on EMH Catalog Contents as of January 31, 2017

3.6 W2_Water Quality

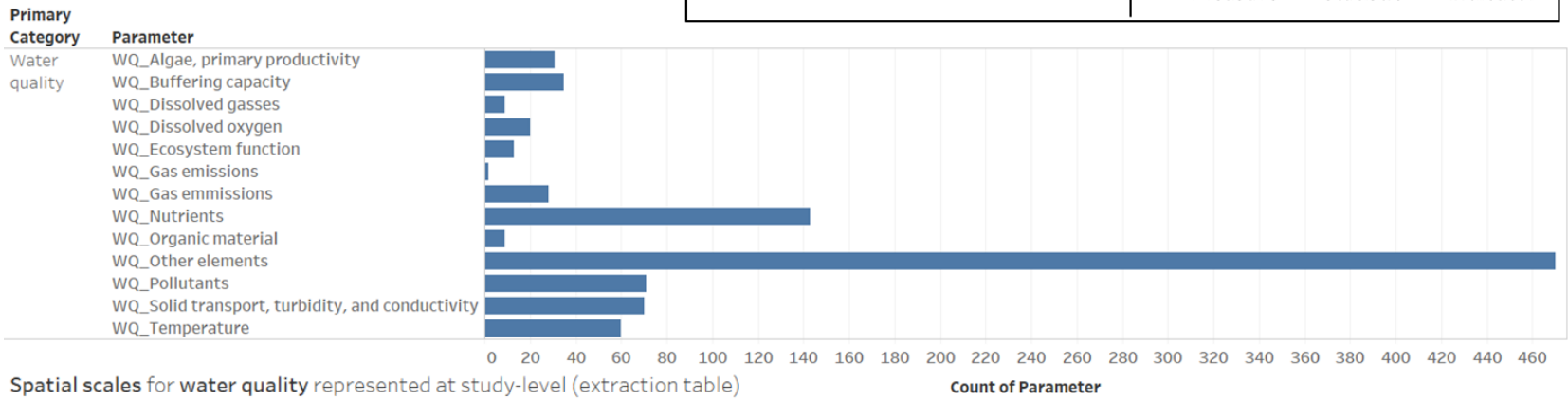
Water quality characteristics such as the temperature and concentrations of dissolved oxygen, velocity, nutrients, and contaminants can be directly or indirectly affected by hydropower development and operation. Changes in water quality can adversely affect the health of humans and wildlife.

W2 Water Quality

Sector	# of studies	# of metrics
IHA	4	38
LIHI	5	8
FERC	5	36
Peer-Reviewed Literature	247	879
Totals	261	961

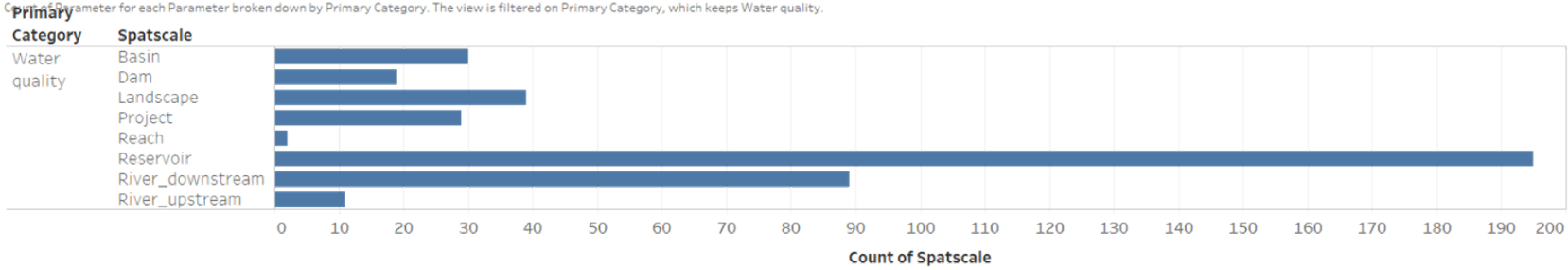


Water quality parameter frequency at study-level (extraction table)



Spatial scales for **water quality** represented at study-level (extraction table)

Count of Parameter for each Parameter broken down by Primary Category. The view is filtered on Primary Category, which keeps Water quality.



Count of Spatscale for each Spatscale broken down by Primary Category.

Frequencies based on EMH Catalog Contents as of January 31, 2017

3.6.1 W2_Algae, Primary Productivity

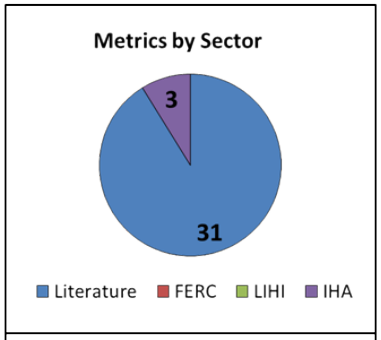
6

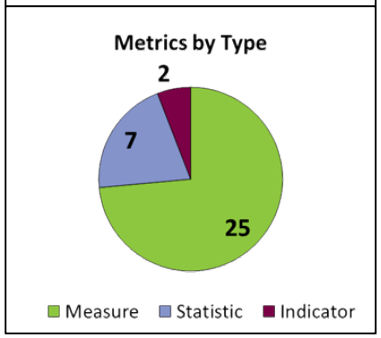
W2 Water Quality

W2_Algae, primary productivity

Algal concentration, including measures of primary productivity such as chlorophyll A or cyanotoxin

Sector	studies	metrics
IHA	4	3
LIHI	5	0
FERC	5	0
Peer-Reviewed Literature	247	31
Totals	261	34





Metric Type	Metric Name
Measure	Benthic light availability
Measure	Biochemical oxygen demand
Measure	Broad band photosynthetically active radiation
Measure	Chlorophyl a abundance
Measure	Chlorophyll a
Measure	Chlorophyll a abundance
Measure	Downwelling irradiance
Measure	Downwelling irradiance; Attenuation coefficient at depth z
Measure	Eutrophication
Measure	Individual particle analysis in per area volume
Measure	Irradiance
Measure	Irradiance cosine
Measure	Irradiance; Attenuation coefficient at depth z
Measure	Reflectance
Measure	Scalar irradiance
Measure	Seston
Measure	Spectral downwelling irradiance
Measure	Total chlorophyll
Measure	Transimissometry
Measure	Upwelling irradiance
Measure	Water column food availability
Statistic	Absorption coefficient
Statistic	Modeled reservoir algae levels
Statistic	Scattering coefficient

Metric Type	Metric Name
Statistic	Spectral average absorption coefficient for gelbstoff
Statistic	Spectral average absorption coefficient for particles
Statistic	Spectral average absorption coefficient for water
Statistic	Water depth euphotic zone
Indicator	Monitoring of algal blooms
Indicator	Monitoring of algal proliferation compared to baseline

Frequencies based on EMH Catalog Contents as of January 31, 2017

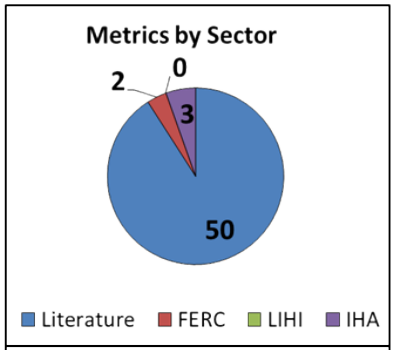
3.6.2 W2_Buffering Capacity

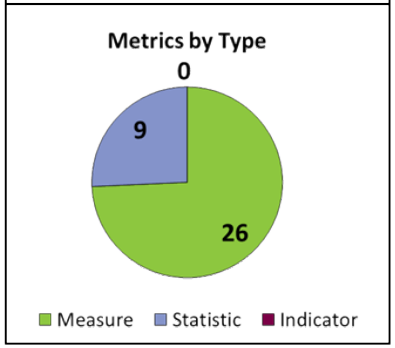
W2 Water Quality

W2_Buffering capacity

Characteristics including pH, alkalinity

Sector	studies	metrics
IHA	4	3
LIHI	5	0
FERC	5	2
Peer-Reviewed Literature	247	50
Totals	261	55





Metric Type	Metric Name
Measure	Alkalinity
Measure	Auditing of pH
Measure	Baseline sampling of pH in river and tributaries
Measure	ph
Measure	pH groundwater
Measure	pH reservoir outlet
Measure	pH river
Measure	pH river downstream
Measure	Quarterly pH measurements
Measure	Reservoir alkalinity
Measure	Reservoir pH
Measure	Stream alkalinity
Measure	Stream pH
Measure	Total alkalinity
Measure	Total hardness
Statistic	Conductivity epilimnion-- average
Statistic	Conductivity hypolimnion-- average
Statistic	Conductivity surface-- average
Statistic	pH epilimnion-- average
Statistic	pH hypolimnion-- average
Statistic	pH surface-- average
Statistic	Total dissolved solids epilimnion-- average
Statistic	Total dissolved solids hypolimnion-- average
Statistic	Total dissolved solids surface-- average

Frequencies based on EMH Catalog Contents as of January 31, 2017

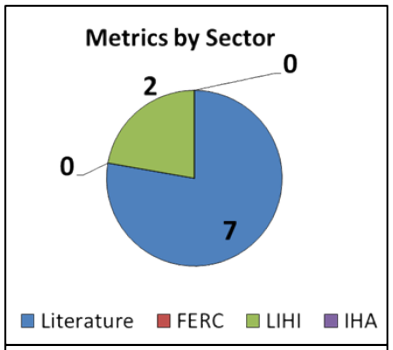
3.6.3 W2_Dissolved Gasses

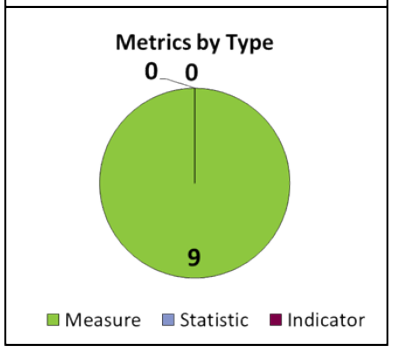
W2 Water Quality

W2_Dissolved gasses

Concentration of non-greenhouse gases in water

Sector	studies	metrics
IHA	4	0
LIHI	5	2
FERC	5	0
Peer-Reviewed Literature	247	7
Totals	261	9





Metric Type	Metric Name
Measure	Carbon dioxide concentration in water
Measure	Gas bubble trauma present
Measure	Methane concentration in water
Measure	Methane in surface water
Measure	Reservoir DO
Measure	Stream DO
Measure	Total dissolved gas
Measure	Total dissolved gases
Measure	Total dissolved gases-- percent saturation

Frequencies based on EMH Catalog Contents as of January 31, 2017

3.6.4 W2_Dissovled Oxygen

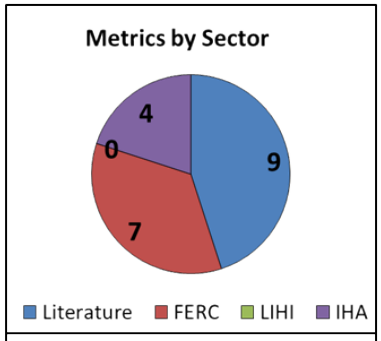
6

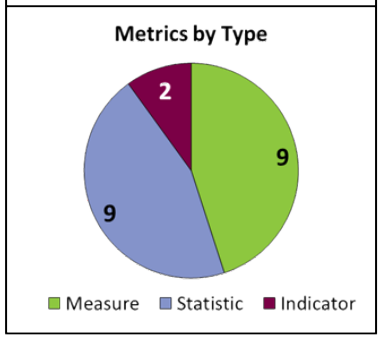
W2 Water Quality

W2_Dissolved oxygen

Dissolved oxygen in water

Sector	studies	metrics
IHA	4	4
LIHI	5	0
FERC	5	7
Peer-Reviewed Literature	247	9
Totals	261	20





Metric Type	Metric Name
Measure	Auditing of dissolved oxygen
Measure	Dissolved oxygen
Measure	Quarterly oxygen level measurements
Measure	Sediment interstitial water dissolved oxygen
Statistic	Dissolved oxygen-- minimum average daily
Statistic	Dissolved oxygen profile
Statistic	Dissolved oxygen reservoir-- minimum
Statistic	Dissolved oxygen reservoir-- range
Statistic	Dissolved oxygen river downstream-- range subdaily
Statistic	Dissolved oxygen river downtream-- range
Statistic	Modeled downstream dissolved oxygen levels
Statistic	Modeled reservoir dissolved oxygen levels
Statistic	Sediment interstitial water dissolved oxygen-- profile
Indicator	Dissolved oxygen longitudinal/ development change
Indicator	Dissolved oxygen percent criteria exceedance

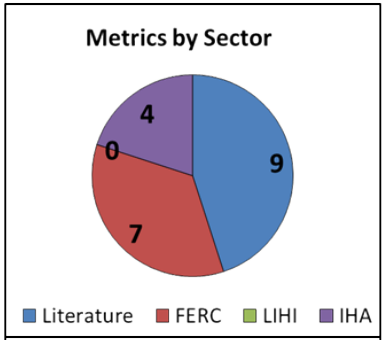
Frequencies based on EMH Catalog Contents as of January 31, 2017

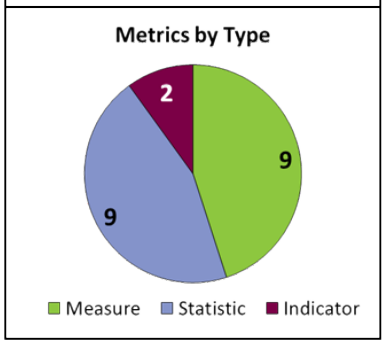
3.6.5 W2_Dissolved Oxygen

W2_Dissolved oxygen

Dissolved oxygen in water

Sector	studies	metrics
IHA	4	4
LIHI	5	0
FERC	5	7
Peer-Reviewed Literature	247	9
Totals	261	20





Metric Type	Metric Name
Measure	Auditing of dissolved oxygen
Measure	Dissolved oxygen
Measure	Quarterly oxygen level measurements
Measure	Sediment interstitial water dissolved oxygen
Statistic	Dissolved oxygen-- minimum average daily
Statistic	Dissolved oxygen profile
Statistic	Dissolved oxygen reservoir-- minimum
Statistic	Dissolved oxygen reservoir-- range
Statistic	Dissolved oxygen river downstream-- range subdaily
Statistic	Dissolved oxygen river downtream-- range
Statistic	Modeled downstream dissolved oxygen levels
Statistic	Modeled reservoir dissolved oxygen levels
Statistic	Sediment interstitial water dissolved oxygen-- profile
Indicator	Dissolved oxygen longitudinal/ development change
Indicator	Dissolved oxygen percent criteria exceedance

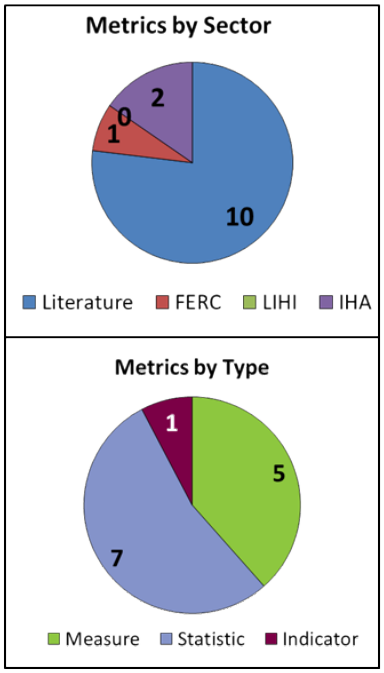
Frequencies based on EMH Catalog Contents as of January 31, 2017

3.6.6 W2_Ecosytem Function

W2_Ecosystem function

Ecosystem vital rates and processes, including gross primary productivity, respiration, biochemical oxygen demand

Sector	studies	metrics
IHA	4	2
LIHI	5	0
FERC	5	1
Peer-Reviewed Literature	247	10
Totals	261	13



Metric Type	Metric Name
Measure	Auditing of BOD
Measure	Baseline sampling of biological oxygen demand in river and tributaries
Measure	Biological oxygen demand
Measure	Chemical oxygen demand
Statistic	Biochemical oxygen demand deoxygenation rate
Statistic	Fraction of dead phytoplankton recycled to dissolved organic nitrogen
Statistic	Fraction of dead phytoplankton recycled to dissolved organic phosphorous
Statistic	Mineralization rate
Statistic	Mineralization rate of dissolved organic phosphorous
Statistic	Nitrification rate
Statistic	Sediment oxygen demand
Indicator	Wetland function loss

Frequencies based on EMH Catalog Contents as of January 31, 2017

3.6.7 W2_Gas Emissions

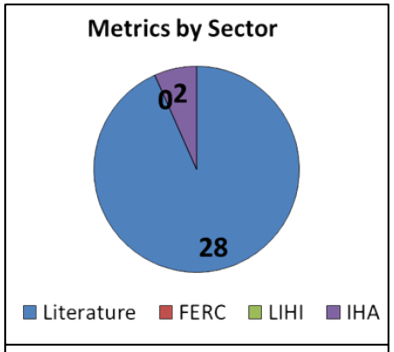
6

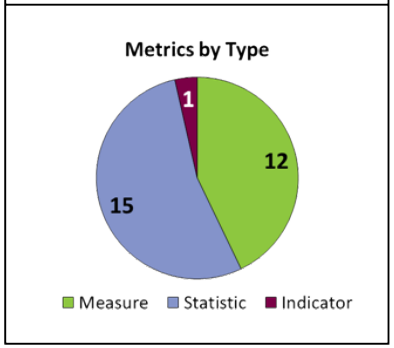
W2 Water Quality

W2_Gas emissions

Concentration and ebullition of water-origin greenhouse gasses

Sector	studies	metrics
IHA	4	2
LIHI	5	0
FERC	5	0
Peer-Reviewed Literature	247	28
Totals	261	30





Metric Type	Metric Name
Measure	Carbon dioxide emissions-- air-water interface
Measure	Carbon dioxide emissions at soil-water interface
Measure	Carbon dioxide emissions-- average soil
Measure	Carbon dioxide flux in air
Measure	Methane emissions
Measure	Methane emissions-- air-water interface
Measure	Methane emissions at soil-water interface
Measure	Methane emissions-- average soil
Measure	Methane flux in air
Measure	Spillway methane emissions
Measure	Surface methane emissions
Measure	Turbine methane emissions
Statistic	Carbon dioxide emissions-- average flooded forest
Statistic	Carbon dioxide emissions-- average flooded peatland
Statistic	Carbon dioxide emissions-- average soil forest
Statistic	Carbon dioxide emissions-- average soil peatland
Statistic	Carbon dioxide emissions-- average soil-water interface forest
Statistic	Carbon dioxide emissions-- average soil-water interface peatland
Statistic	Greenhouse gas emissions
Statistic	Methane emissions-- average flooded forest
Statistic	Methane emissions-- average flooded peatland
Statistic	Methane emissions-- average soil forest
Statistic	Methane emissions-- average soil peatland
Statistic	Methane emissions-- average soil-water interface forest
Statistic	Methane emissions-- average soil-water interface peatland
Statistic	Methane flux-- annual
Statistic	Post-impoundment greenhouse gas emission
Indicator	Environmental premium

Frequencies based on EMH Catalog Contents as of January 31, 2017

3.6.8 W2_Nutrients

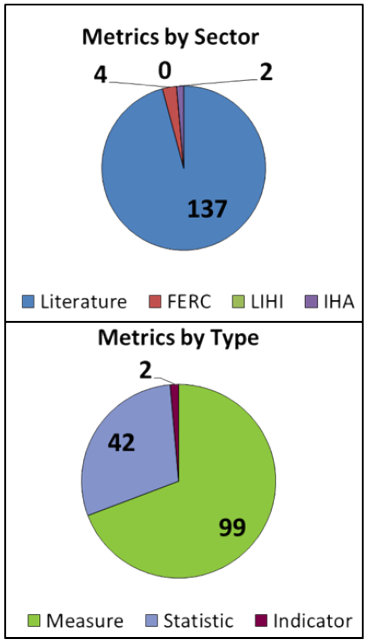
6

W2 Water Quality

W2_Nutrients

All non-rare elements essential to life: nitrogen, phosphorous, inorganic carbon, potassium, sulfur, and magnesium compounds (rare essential elements are included in "other elements")

Sector	studies	metrics
IHA	4	2
LIHI	5	0
FERC	5	4
Peer-Reviewed Literature	247	137
Totals	261	143



Metric Type	Metric Name
Measure	Algae bloom reservoir present
Measure	Ammonia
Measure	Ammonium
Measure	Ammonium reservoir outlet
Measure	Bank sediment-- calcium concentration
Measure	Bank sediment-- chlorine concentration
Measure	Bank sediment-- magnesium concentration
Measure	Bank sediment-- phosphorous concentration
Measure	Bank sediment-- potassium concentration
Measure	Bank sediment-- sodium concentration
Measure	Bank sediment-- sulfur concentration
Measure	Baseline sampling of nutrients in river and tributaries
Measure	Calcium
Measure	Calcium concentration groundwater
Measure	Calcium concentration river
Measure	Calcium concentrations sediment
Measure	Carbon dioxide concentration river
Measure	Dissolved inorganic nitrogen concentration
Measure	Dissolved inorganic nitrogen reservoir outlet
Measure	Dissolved inorganic phosphorous concentration
Measure	Magnesium concentration sediment
Measure	Nitrate
Measure	Nitrogen saturation below turbines
Measure	Nitrogen saturation forebay
Measure	Nitrogen saturation forebay above turbines
Measure	Nitrogen saturation stilling basin
Measure	Nutrient levels reservoir
Measure	Nutrient levels-- reservoir
Measure	Organic nitrogen
Measure	Organic phosphorous
Measure	Orthophosphate

Metric Type	Metric Name
Measure	Particulate nitrogen reservoir outlet
Measure	Phosphate
Measure	Phosphorous concentration sediment
Measure	Potassium concentration river
Measure	Potassium concentration sediment
Measure	Sodium
Measure	Sodium oxate concentration
Measure	Soluble reactive phosphorous
Measure	Soluble reactive phosphorous reservoir outlet
Measure	Suspended sediment-- calcium concentration
Measure	Suspended sediment-- magnesium concentration
Measure	Suspended sediment-- phosphorous concentration
Measure	Suspended sediment-- potassium concentration
Measure	Suspended sediment-- sodium concentration
Measure	Suspended sediment-- sulfur concentration
Measure	Total dissolved nitrogen reservoir outlet
Measure	Total Kjeldahl nitrogen
Measure	Total nitrogen
Measure	Total organic matter in sediment
Measure	Total phosphorous
Measure	Total phosphorous in sediment
Measure	Total phosphorous inflow
Measure	Total phosphorous outflow
Measure	Totalk Kjeldahl nitrogen minus ammonia/ ammonium
Measure	Water nutrients - Ammonium
Measure	Water nutrients - Nitrate
Measure	Water nutrients - Nitrite
Measure	Water nutrients - SRP

Frequencies based on EMH Catalog Contents as of January 31, 2017

6

W2_Nutrients

All non-rare elements essential to life: nitrogen, phosphorous, inorganic carbon, potassium, sulfur, and magnesium compounds (rare essential elements are included in "other elements")

W2 Water Quality

Metric Type	Metric Name
Measure	Water nutrients - Total P
Statistic	Ammonia epilimnion-- average
Statistic	Ammonia hypolimnion-- average
Statistic	Ammonia surface-- average
Statistic	Bicarbonate epilimnion-- average
Statistic	Bicarbonate hypolimnion-- average
Statistic	Bicarbonate surface-- average
Statistic	Calcium epilimnion-- average
Statistic	Calcium hypolimnion-- average
Statistic	Calcium surface-- average
Statistic	Dissolved inorganic nitrogen load
Statistic	Dissolved inorganic phosphorous load
Statistic	Magnesium epilimnion-- average
Statistic	Magnesium hypolimnion-- average
Statistic	Magnesium surface-- average
Statistic	Net accumulation of phosphorous in reservoir
Statistic	Nitrate epilimnion-- average
Statistic	Nitrate hypolimnion-- average
Statistic	Nitrate surface-- average
Statistic	Nitrogen saturation below turbines-- average daily
Statistic	Nitrogen saturation below turbines-- average seasonal
Statistic	Nitrogen saturation forebay above spillway-- average daily
Statistic	Nitrogen saturation forebay above spillway-- average seasonal
Statistic	Nitrogen saturation forebay above turbines-- average daily
Statistic	Nitrogen saturation forebay above turbines-- average seasonal

Metric Type	Metric Name
Statistic	Nitrogen saturation stilling basin-- average daily
Statistic	Nitrogen saturation stilling basin-- average seasonal
Statistic	Percent by weight carbonate fraction
Statistic	Phosphate epilimnion-- average
Statistic	Phosphate hypolimnion-- average
Statistic	Phosphate surface-- average
Statistic	Potassium to gallium ratio
Statistic	Ratio of strontium 87 isotope to strontium 86 isotope
Statistic	Sodium epilimnion-- average
Statistic	Sodium hypolimnion-- average
Statistic	Sodium surface-- average
Statistic	Sulfate epilimnion-- average
Statistic	Sulfate hypolimnion-- average
Statistic	Sulfate surface-- average
Indicator	Nutrient levels construction discharge
Indicator	Nutrient monitoring

Frequencies based on EMH Catalog Contents as of January 31, 2017

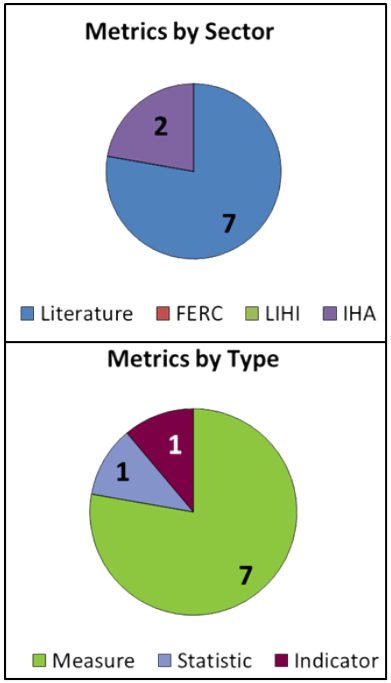
3.6.9 W2_Organic Material

W2_Organic material

Dissolved organic carbon and other organic non-pollutants

Sector	studies	metrics
IHA	4	2
LIHI	5	0
FERC	5	0
Peer-Reviewed Literature	247	7
Totals	261	9

Metric Type	Metric Name
Measure	Chromorphic organic matter
Measure	Dissolved Organic Carbon
Measure	Organic siltation
Measure	Total organic matter
Statistic	Modeled reservoir carbon load
Indicator	Baseline microbiological parameters



Frequencies based on EMH Catalog Contents as of January 31, 2017

3.6.10 W2_Other elements

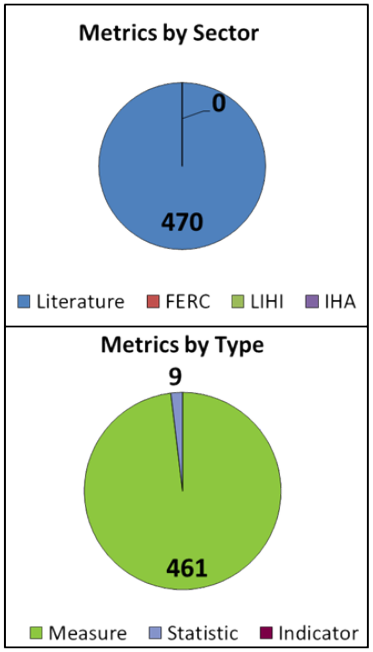
6

W2 Water Quality

W2_Other elements

Elements and compounds that are not listed on the EPA Toxic and Priority Pollutants list

Sector	studies	metrics
IHA	4	0
LIHI	5	0
FERC	5	0
Peer-Reviewed Literature	247	470
Totals	261	470



Metric Type	Metric Name
Measure	Bank sediment-- antimony concentration
Measure	Bank sediment-- barium concentration
Measure	Bank sediment-- beryllium concentration
Measure	Bank sediment-- bismuth concentration
Measure	Bank sediment-- boron concentration
Measure	Bank sediment-- bromium concentration
Measure	Bank sediment-- cadmium concentration
Measure	Bank sediment-- cerium concentration
Measure	Bank sediment-- chromium concentration
Measure	Bank sediment-- cobalt concentration
Measure	Bank sediment-- copper concentration
Measure	Bank sediment-- dysprosium concentration
Measure	Bank sediment-- erbium concentration
Measure	Bank sediment-- europium concentration
Measure	Bank sediment-- gadolinium concentration
Measure	Bank sediment-- gallium concentration
Measure	Bank sediment-- gold concentration
Measure	Bank sediment-- hafnium concentration

Metric Type	Metric Name
Measure	Bank sediment-- holmium concentration
Measure	Bank sediment-- iron concentration
Measure	Bank sediment-- lanthanum concentration
Measure	Bank sediment-- lithium concentration
Measure	Bank sediment-- lutetium concentration
Measure	Bank sediment-- magnesium concentration
Measure	Bank sediment-- mananese concentration
Measure	Bank sediment-- molybdenum concentration
Measure	Bank sediment-- neodymium concentration
Measure	Bank sediment-- nickel concentration
Measure	Bank sediment-- niobium concentration
Measure	Bank sediment-- platinum concentration
Measure	Bank sediment-- praseodymium concentration
Measure	Bank sediment-- rubidium concentration
Measure	Bank sediment-- samarium concentration
Measure	Bank sediment-- scandium concentration
Measure	Bank sediment-- silicon concentration
Measure	Bank sediment-- silver concentration

Frequencies based on EMH Catalog Contents as of January 31, 2017

6

W2_Other elements

Elements and compounds that are not listed on the EPA Toxic and Priority Pollutants list

W2 Water Quality

Metric Type	Metric Name
Measure	Bank sediment-- strontium concentration
Measure	Bank sediment-- tantalum concentration
Measure	Bank sediment-- terbium concentration
Measure	Bank sediment-- thallium concentration
Measure	Bank sediment-- thorium concentration
Measure	Bank sediment-- thulium concentration
Measure	Bank sediment-- tin concentration
Measure	Bank sediment-- titanium concentration
Measure	Bank sediment-- tungsten concentration
Measure	Bank sediment-- uranium concentration
Measure	Bank sediment-- vanadium concentration
Measure	Bank sediment-- ytterbium concentration
Measure	Bank sediment-- yttrium concentration
Measure	Bank sediment-- zinc concentration
Measure	Bank sediment-- zirconium concentration
Measure	Chloride
Measure	Chromium
Measure	Dissolved iron reservoir outlet
Measure	Dissolved silica concentration

Metric Type	Metric Name
Measure	Groundwater-- carbon dioxide concentration
Measure	Groundwater-- chlorine concentration
Measure	Groundwater-- potassium concentration
Measure	Groundwater-- sodium concentration
Measure	Groundwater-- sulfate concentration
Measure	Iron
Measure	Iron concentration--sediment
Measure	Iron concentration--water
Measure	Lead
Measure	Manganese
Measure	Manganese concentration--sediment
Measure	Manganese concentration--water
Measure	Nickel
Measure	Oxidation reduction potential reservoir outlet
Measure	Sediment-- copper concentration
Measure	Sediment-- aluminum concentration
Measure	Sediment-- barium concentration
Measure	Sediment-- bicarbonate concentration
Measure	Sediment-- cadmium concentration
Measure	Sediment-- cesium concentration
Measure	Sediment-- chromium concentration
Measure	Sediment-- copper concentration
Measure	Sediment-- iron concentration
Measure	Sediment-- lead concentration
Measure	Sediment-- manganese concentration
Measure	Sediment-- nickel concentration

Metric Type	Metric Name
Measure	Sediment-- rubidium concentration
Measure	Sediment-- silicon concentration
Measure	Sediment-- sodium concentration
Measure	Sediment-- strontium concentration
Measure	Sediment-- titanium concentration
Measure	Sediment-- vanadium concentration
Measure	Sediment-- zinc concentration
Measure	Sediment-- zirconium concentration
Measure	Silicate
Measure	Sulfate
Measure	Suspended sediment-- antimony concentration
Measure	Suspended sediment-- arsenic concentration
Measure	Suspended sediment-- barium concentration
Measure	Suspended sediment-- beryllium concentration
Measure	Suspended sediment-- bismuth concentration
Measure	Suspended sediment-- boron concentration
Measure	Suspended sediment-- bromium concentration
Measure	Suspended sediment-- cadmium concentration
Measure	Suspended sediment-- cerium concentration
Measure	Suspended sediment-- chromium concentration
Measure	Suspended sediment-- cobalt concentration

Frequencies based on EMH Catalog Contents as of January 31, 2017

6

W2_Other elements

Elements and compounds that are not listed on the EPA Toxic and Priority Pollutants list

W2 Water Quality

Metric Type	Metric Name
Measure	Suspended sediment-- copper concentration
Measure	Suspended sediment-- dysprosium concentration
Measure	Suspended sediment-- erbium concentration
Measure	Suspended sediment-- europium concentration
Measure	Suspended sediment-- gadolinium concentration
Measure	Suspended sediment-- gallium concentration
Measure	Suspended sediment-- gold concentration
Measure	Suspended sediment-- hafnium concentration
Measure	Suspended sediment-- holmium concentration
Measure	Suspended sediment-- iron concentration
Measure	Suspended sediment-- lanthanum concentration
Measure	Suspended sediment-- lithium concentration
Measure	Suspended sediment-- lutetium concentration
Measure	Suspended sediment-- mananese concentration
Measure	Suspended sediment-- molybdenum concentration
Measure	Suspended sediment-- neodymium concentration

Metric Type	Metric Name
Measure	Suspended sediment-- nickel concentration
Measure	Suspended sediment-- niobium concentration
Measure	Suspended sediment-- phosphorous concentration
Measure	Suspended sediment-- platinum concentration
Measure	Suspended sediment-- praseodymium concentration
Measure	Suspended sediment-- rubidium concentration
Measure	Suspended sediment-- samarium concentration
Measure	Suspended sediment-- scandium concentration
Measure	Suspended sediment-- selenium concentration
Measure	Suspended sediment-- silicon concentration
Measure	Suspended sediment-- silver concentration
Measure	Suspended sediment-- sodium concentration
Measure	Suspended sediment-- strontium concentration
Measure	Suspended sediment-- tantalum concentration
Measure	Suspended sediment-- terbium concentration
Measure	Suspended sediment-- thallium concentration

Metric Type	Metric Name
Measure	Suspended sediment-- thorium concentration
Measure	Suspended sediment-- thulium concentration
Measure	Suspended sediment-- tin concentration
Measure	Suspended sediment-- titanium concentration
Measure	Suspended sediment-- tungsten concentration
Measure	Suspended sediment-- uranium concentration
Measure	Suspended sediment-- vanadium concentration
Measure	Suspended sediment-- ytterbium concentration
Measure	Suspended sediment-- yttrium concentration
Measure	Suspended sediment-- zinc concentration
Measure	Suspended sediment-- zirconium concentration
Measure	Upwelling irradiance
Measure	Water-- bicarbonate concentration river
Measure	Water-- cadmium concentration
Measure	Water-- chlorine concentration river
Measure	Water elements - Chloride
Measure	Water-- sodium concentration river
Measure	Water-- sulfate concentration river
Measure	Zinc
Statistic	Dissolved silica load

Frequencies based on EMH Catalog Contents as of January 31, 2017

6

W2_Other elements

Elements and compounds that are not listed on the EPA Toxic and Priority Pollutants list

W2 Water Quality

Metric Type	Metric Name
Statistic	Iron epilimnion-- average
Statistic	Iron hypolimnion-- average
Statistic	Iron surface-- average
Statistic	Manganese epilimnion-- average
Statistic	Manganese hypolimnion-- average
Statistic	Manganese surface-- average
Statistic	Ratio of strontium 87 isotope to strontium 86 isotope

3.6.11 W2_Pollutants

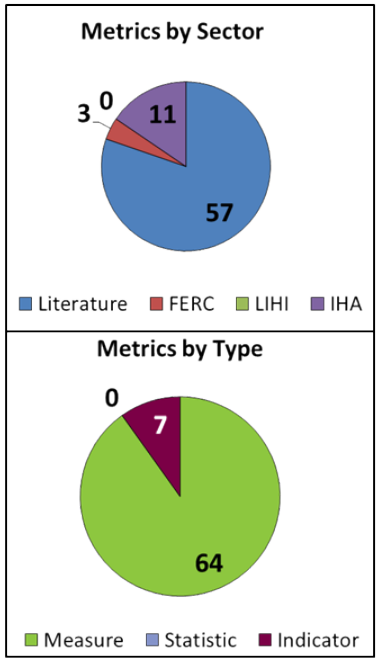
6

W2 Water Quality

W2_Pollutants

Pollutants listed on the EPA Toxic and Priority Pollutants list that are not included in other EMH categories

Sector	studies	metrics
IHA	4	11
LIHI	5	0
FERC	5	3
Peer-Reviewed Literature	247	57
Totals	261	71



Metric Type	Metric Name
Measure	Bacterial concentration
Measure	Bank sediment-- aluminum concentration
Measure	Bank sediment-- arsenic concentration
Measure	Bank sediment-- lead concentration
Measure	Bank sediment-- selenium concentration
Measure	Baseline sampling of toxic and priority pollutants in river and tributaries
Measure	Coliform counts
Measure	E coli
Measure	E. coli monitoring
Measure	Fecal coliform
Measure	Lead
Measure	Lead concentration--sediment
Measure	Lead concentration--water
Measure	Monthly water quality tests against drinking water standards
Measure	Oil and grease
Measure	Organic pollution
Measure	Sediment-- arsenic concentration
Measure	Sediment-- mercury concentration
Measure	Suspended sediment-- aluminum concentration
Measure	Suspended sediment-- arsenic concentration
Measure	Suspended sediment-- lead concentration
Measure	Suspended sediment-- selenium concentration
Measure	Test for industrial effluent limits
Measure	Total coliform
Measure	Toxic substances
Measure	Water-- arsenic concentration
Measure	Water-- mercury concentration
Indicator	Bacterial concentration construction discharge

Metric Type	Metric Name
Indicator	Baseline physical & chemical parameters
Indicator	Baseline water quality
Indicator	CCME Water Quality Index
Indicator	Ongoing, comprehensive water quality monitoring
Indicator	Toxic construction discharge
Indicator	Water quality index score

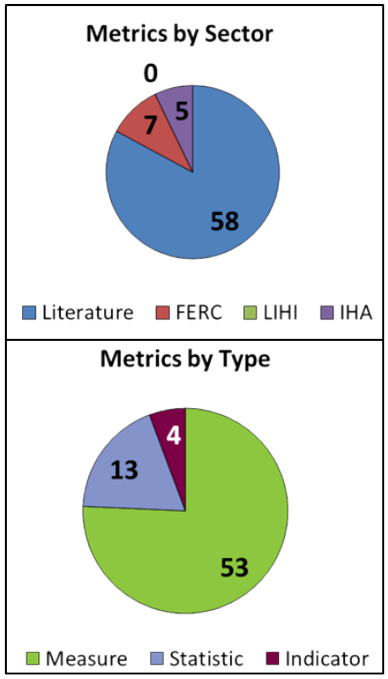
Frequencies based on EMH Catalog Contents as of January 31, 2017

3.6.12 W2_Solid Transport, Turbidity & Conductivity

W2_Solid transport, turbidity & conductivity

Descriptions of dissolved and suspended solids in water such as turbidity, suspended or dissolved solids, conductance

Sector	studies	metrics
IHA	4	5
LIHI	5	0
FERC	5	7
Peer-Reviewed Literature	247	58
Totals	261	70



Metric Type	Metric Name
Measure	Baseline sampling of electrical conductivity, dissolved solids and TSS in river and tributaries
Measure	Color
Measure	Conductivity
Measure	Conductivity river downstream
Measure	Continuous sediment load monitoring
Measure	Quarterly conductivity measurements
Measure	Reservoir conductivity
Measure	Reservoir secchi depth
Measure	Salinity
Measure	Salinity surface
Measure	Secchi depth
Measure	Sediment loading reservoir
Measure	Specific conductance
Measure	Stream conductivity
Measure	Stream secchi depth
Measure	Suspended sediment
Measure	Suspended sediment discharge
Measure	Suspended sediment sampling
Measure	Suspended solids
Measure	Total dissolved soilds upper layer of reservoir water
Measure	Total dissolved solids
Measure	Total dissolved solids concentration river
Measure	Total dissolved solids in groundwater
Measure	Total dissolved solids lower layer of reservoir water
Measure	Total dissolved solids middle layer of reservoir water

Metric Type	Metric Name
Measure	Total suspended solids
Measure	Turbidity
Measure	Turbidity and sediment concentration
Statistic	Salinity -- average monthly
Statistic	Salinity reservoir inflow-- average monthly
Statistic	Secchi depth-- average
Statistic	Solids flow specification
Statistic	Suspended sediment concentration-- monthly
Statistic	Suspended sediment concentration-- yearly
Statistic	Suspended sediment-- daily
Statistic	Total sediment discharge-- annual
Statistic	Total sediment discharge-- daily
Statistic	Total sediment discharge-- month
Statistic	Turbidity-- average monthly
Indicator	Baseline surveys of total suspended sediments
Indicator	Erosion construction and excavation

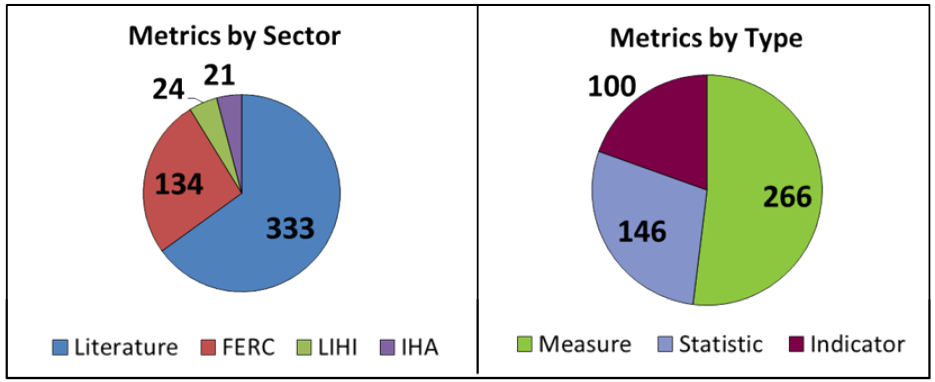
Frequencies based on EMH Catalog Contents as of January 31, 2017

3.7 BB_Biota and Biodiversity

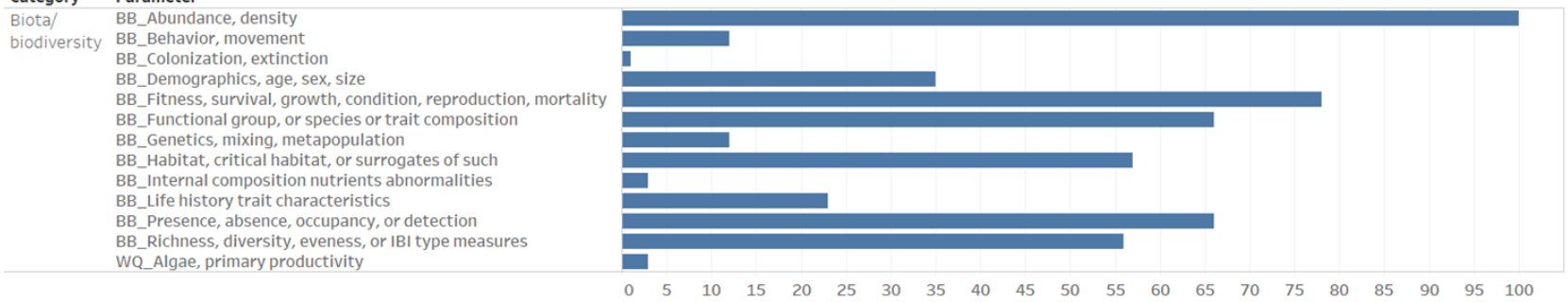
BB Biota and Biodiversity

The types of plant and animal species found in a watershed, as well as their absolute abundance and abundance relative to one another, reflect the overall health of an ecosystem. Shifts in aquatic, riparian, and terrestrial populations and communities have been linked to several aspects of hydropower construction and operation, including decreased longitudinal connectivity and changes in flow velocities in rivers, inundation of uplands upstream of dams, changes in groundwater depth both up- and downstream of dams, and changes in sediment and flow regimes. Identifying metrics to accurately assess population and community changes is essential to understanding the environmental effects of hydropower.

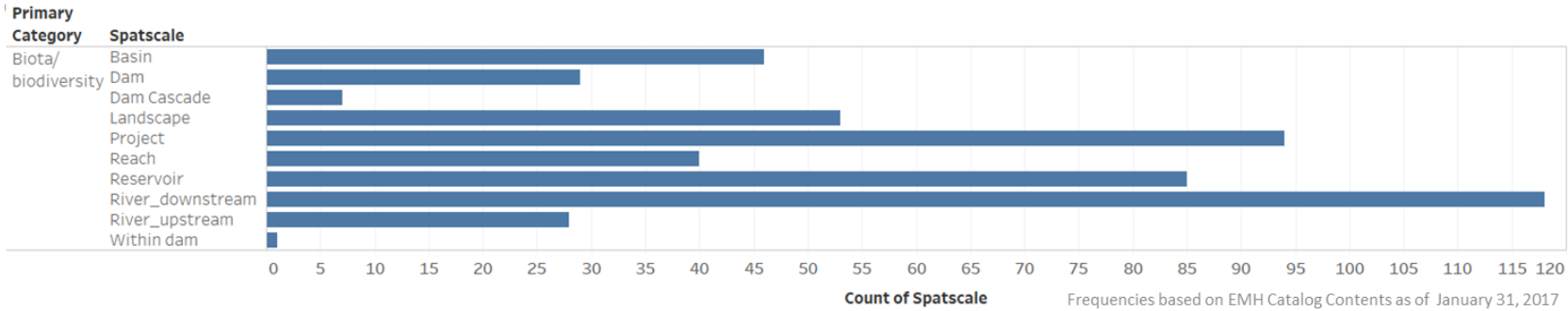
Sector	# of studies	# of metrics
IHA	4	21
LIHI	5	24
FERC	5	134
Peer-Reviewed Literature	247	333
Totals	261	512



Biota parameter frequency at study-level (extraction table)



Spatial scales for **biota** represented at study-level (extraction table)



Frequencies based on EMH Catalog Contents as of January 31, 2017

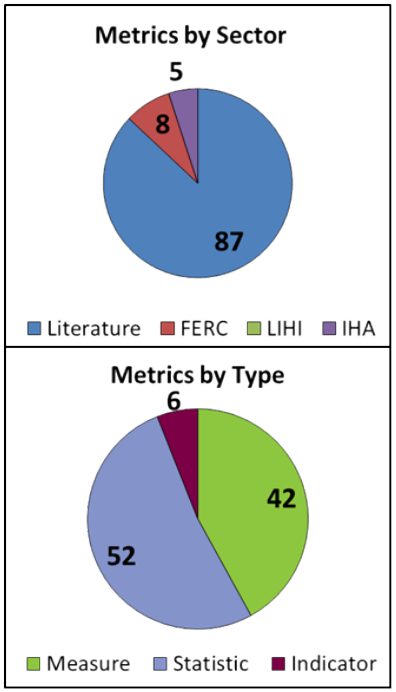
3.7.1 BB_Abundance, density

BB Biota and Biodiversity

BB_Abundance, density

Count or other measures of organisms per area

Sector	studies	metrics
IHA	4	5
LIHI	5	0
FERC	5	8
Peer-Reviewed Literature	247	87
Totals	261	100



Metric Type	Metric Name
Measure	Basal cover
Measure	Benthic food availability
Measure	Bird abundance
Measure	Cyanobacteria abundance
Measure	Diatom abundance
Measure	Fish abundance
Measure	Fish biomass
Measure	Fish catch per unit effort
Measure	Fish larval/egg abundance
Measure	Fish migratory abundance
Measure	Fish population size
Measure	Fish species abundance
Measure	Fish species presence-absence
Measure	Fish species richness
Measure	Host fish abundance
Measure	Macroinvertebrate abundance
Measure	Macroinvertebrate taxa abundance
Measure	Migratory fish abundance
Measure	Mussel population size
Measure	Quarterly abundance counts of terrestrial species
Measure	Vegetation biomass
Statistic	Deer abundance
Statistic	Fish abundance - max
Statistic	Fish abundance - min
Statistic	Fish catch per unit effort
Statistic	Fish catch per unit effort - average
Statistic	Fish population biomass
Statistic	Fish population density
Statistic	Fish population density age-class
Statistic	Fish population size
Statistic	Fish total catch
Statistic	Fish YOY density
Statistic	Goat abundance

Metric Type	Metric Name
Statistic	Macroinvertebrate density
Statistic	Macroinvertebrate drift density
Statistic	Macrophyte abundance Domin-Krajina
Statistic	Macrophyte coverage
Statistic	Mussel population density
Statistic	Non-native Mussel density
Statistic	Non-native Mussel larval abundance
Statistic	Phytoplankton abundance
Statistic	Phytoplankton biomass
Statistic	Tree abundance - basal area
Statistic	Tree abundance - volume
Statistic	Tree density
Statistic	Vegetation abundance
Indicator	Annual fish stock surveys
Indicator	Change Phytoplankton abundance
Indicator	Deviation fish population size
Indicator	Fish
Indicator	Macroinvertebrate sampling
Indicator	Snail surveys

Frequencies based on EMH Catalog Contents as of January 31, 2017

3.7.2 BB_behavior, movement

7

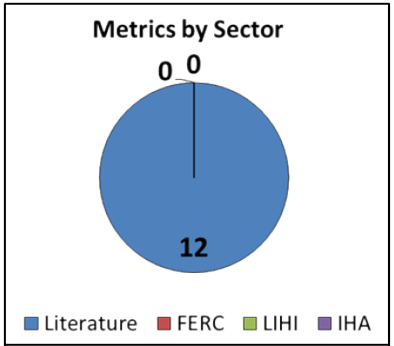
BB Biota and Biodiversity

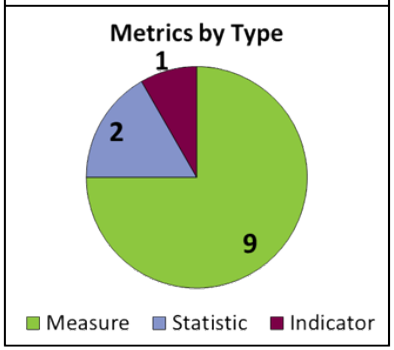
BB_Behavior, movement

Behavior of organisms, including movement pattern, distance, duration, timing, and frequency

Sector	studies	metrics
IHA	4	0
LIHI	5	0
FERC	5	0
Peer-Reviewed Literature	247	12
Totals	261	12

Metric Type	Metric Name
Measure	Fish movement
Measure	Goat behavior 1
Measure	Goat daily movement
Measure	Mussel movement
Measure	Turtle movement
Statistic	Mussel burial - mean
Statistic	Mussel movement - mean
Indicator	Change fish life history characteristic - spawn 2





Frequencies based on EMH Catalog Contents as of January 31, 2017

3.7.3 BB_Colonization, extinction

7

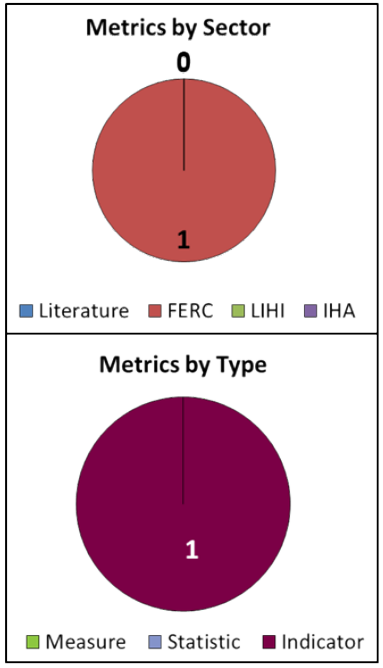
BB Biota and Biodiversity

BB_Colonization, extinction

Colonization or extinction of organisms in a study area

Sector	studies	metrics
IHA	4	0
LIHI	5	0
FERC	5	1
Peer-Reviewed Literature	247	0
Totals	261	1

Metric Type	Metric Name
Indicator	Macroinvertebrate colonization



Frequencies based on EMH Catalog Contents as of January 31, 2017

3.7.4 BB_Demographics, age, sex, size

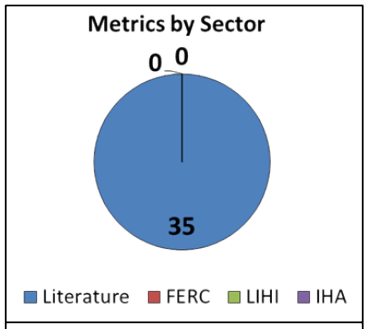
7

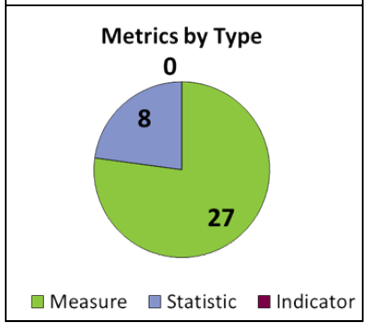
BB Biota and Biodiversity

BB_Demographics, age, sex, size

Population demographics, including age, sex, and size

Sector	studies	metrics
IHA	4	0
LIHI	5	0
FERC	5	0
Peer-Reviewed Literature	247	35
Totals	261	35





Metric Type	Metric Name
Measure	Fish age
Measure	Fish length regulated site
Measure	Fish length unregulated site
Measure	Fish sex
Measure	Fish size
Measure	Goat age
Measure	Goat sex
Measure	Mussel age
Measure	Mussel size
Measure	Phytoplankton size
Measure	Tree size
Statistic	Fish size
Statistic	Fish size - range
Statistic	Fish size age-class
Statistic	Mussel age - %
Statistic	Mussel size - %

Frequencies based on EMH Catalog Contents as of January 31, 2017

3.7.5 BB_Fitness, survival, growth, condition, reproduction, mortality

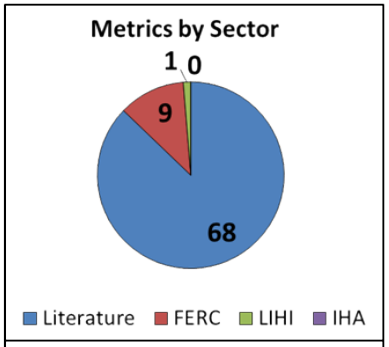
7

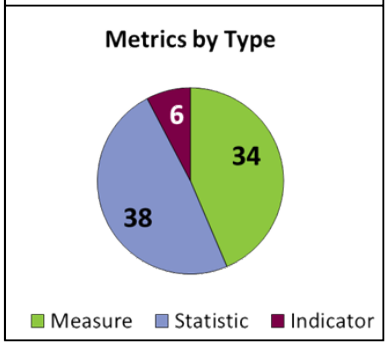
BB Biota and Biodiversity

BB_Fitness, survival, growth, condition, reproduction, mortality

Fitness, survival, growth, condition, reproduction, or mortality of organisms

Sector	studies	metrics
IHA	4	0
LIHI	5	1
FERC	5	9
Peer-Reviewed Literature	247	68
Totals	261	78





Metric Type	Metric Name
Measure	Fish condition - stomach content
Measure	Fish contaminant As concentration
Measure	Fish contaminant Cd concentration
Measure	Fish contaminant Cu concentration
Measure	Fish contaminant Fe concentration
Measure	Fish contaminant Hg concentration
Measure	Fish contaminant Mn concentration
Measure	Fish contaminant Pb concentration
Measure	Fish kills - presence-absence
Measure	Fish mortality
Measure	Fish survival - abundance
Measure	Mussel larval abundance
Measure	Non-native Mussel life history characteristic 1
Measure	Non-predatory phytoplankton death rate
Measure	Phytoplankton growth rate
Measure	Plant contaminant As concentration
Measure	Plant contaminant Cd concentration
Measure	Plant contaminant Cu concentration
Measure	Plant contaminant Fe concentration
Measure	Plant contaminant Hg concentration
Measure	Plant contaminant Mn concentration
Measure	Plant contaminant Pb concentration
Statistic	Fish condition - K
Statistic	Fish condition - stomach:body mass

Metric Type	Metric Name
Statistic	Fish gonadosomatic index
Statistic	Fish growth rate
Statistic	Fish growth rate age-class mean
Statistic	Fish larval/egg abundance
Statistic	Fish mortality - %
Statistic	Fish mortality - average
Statistic	Fish mortality - maximum
Statistic	Fish mortality - minimum
Statistic	Fish mortality rate age-class mean
Statistic	Fish recruitment
Statistic	Fish survival
Statistic	Fish survival - %
Statistic	Fish turbine survival
Statistic	Maximum phytoplankton growth rate
Statistic	Mussel growth rate
Statistic	Mussel mortality - %
Statistic	Mussels stranded - %
Statistic	Percent mortality
Indicator	Fish condition age-class Fulton
Indicator	Fish gonadosomatic index
Indicator	Fish spawning/recruitment
Indicator	Fish YOY survival
Indicator	Mussel Larval Dispersal Indicator
Indicator	Mussel Reproduction Indicator

Frequencies based on EMH Catalog Contents as of January 31, 2017

3.7.6 BB_Functioanl group, or species or trait composition

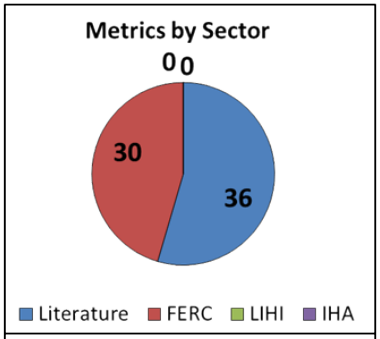
7

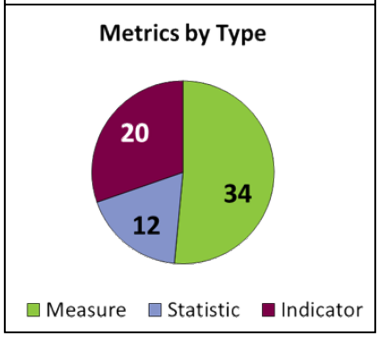
BB Biota and Biodiversity

BB_Functional group, or species or trait composition

Grouping of organisms by functional or trait status, percentage composition

Sector	studies	metrics
IHA	4	0
LIHI	5	0
FERC	5	30
Peer-Reviewed Literature	247	36
Totals	261	66





Metric Type	Metric Name
Measure	Amphibian Species Composition
Measure	Aquatic Mammal Species Composition
Measure	Aquatic Reptile Species Composition
Measure	Bird Wildlife Species Composition
Measure	Butterfly Species Composition
Measure	Fish community composition - broad cast spawning
Measure	Fish community composition - complex spawning
Measure	Fish community composition - Cruiser morphology
Measure	Fish community composition - Feeding guilds (Herbivore/Detritivore)
Measure	Fish community composition - Feeding guilds (Insectivore)
Measure	Fish community composition - Hugger morphology
Measure	Fish Community Composition - life history strategies
Measure	Fish Community Composition - nest type
Measure	Fish community composition - Pool habitat
Measure	Fish community composition - Slackwater habitat
Measure	Fish community species composition
Measure	Macroinvertebrate functional feeding group abundance
Measure	Riparian Vegetation Composition
Measure	Riparian Wildlife Composition
Measure	Terrestrial Mammal Wildlife Composition
Measure	Trout Fishery - Presence-absence
Measure	Upland Vegetation Composition
Measure	Vegetation community species composition
Measure	Vegetation type

Metric Type	Metric Name
Measure	Wetland Vegetation Compostion
Statistic	Change in fish community composition - functional type
Statistic	Fish Community Composition - %
Statistic	Fish Community Composition - historical
Statistic	Fish Species Composition - %
Statistic	Macroinvertebrate community composition - % taxa
Statistic	Macroinvertebrate species richness
Statistic	Natural vegetation assemblage change
Statistic	Natural vegetation assemblage succession
Statistic	Recreational fishing effort - % of time
Statistic	Recreational fishing harvest - % of catch
Indicator	Canadian Ecological Flow Generalist Index
Indicator	Canadian Ecological Flow Specialist Index
Indicator	Change in fish community composition - equilibrium life histories
Indicator	Change in fish community composition - opportunistic life histories
Indicator	Change in fish community composition - periodic life histories
Indicator	Colwater Fisheries - Presence-absence
Indicator	Coolwater Fish Community Indicator
Indicator	Fish Community Composition - %
Indicator	Fish Community Health
Indicator	Fish Taxonomic Distinctiveness Index
Indicator	Fishery Resources Indicator
Indicator	Macroinvertebrate Community Health
Indicator	Riparian vegetation alteration
Indicator	Sportfishing Satisfaction Rating
Indicator	Tree Jaccard's coefficient of community similarity
Indicator	Tree Sorensen's Similarity Index
Indicator	Warmwater Fish Community Indicator

Frequencies based on EMH Catalog Contents as of January 31, 2017

3.7.7 BB_Functional group, or species or trait composition

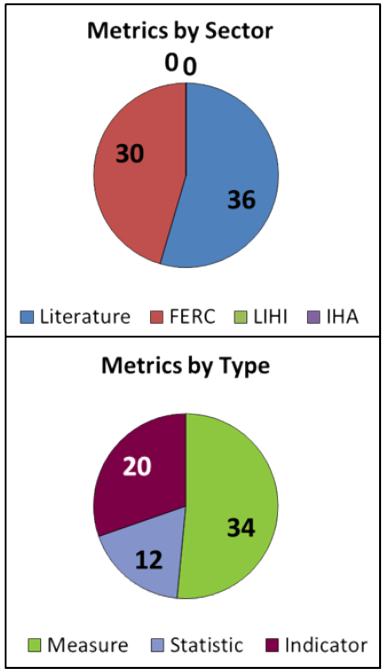
7

BB Biota and Biodiversity

BB_Functional group, or species or trait composition

Grouping of organisms by functional or trait status, percentage composition

Sector	studies	metrics
IHA	4	0
LIHI	5	0
FERC	5	30
Peer-Reviewed Literature	247	36
Totals	261	66



Metric Type	Metric Name
Measure	Amphibian Species Composition
Measure	Aquatic Mammal Species Composition
Measure	Aquatic Reptile Species Composition
Measure	Bird Wildlife Species Composition
Measure	Butterfly Species Composition
Measure	Fish community composition - broad cast spawning
Measure	Fish community composition - complex spawning
Measure	Fish community composition - Cruiser morphology
Measure	Fish community composition - Feeding guilds (Herbivore/Detritivore)
Measure	Fish community composition - Feeding guilds (Insectivore)
Measure	Fish community composition - Hugger morphology
Measure	Fish Community Composition - life history strategies
Measure	Fish Community Composition - nest type
Measure	Fish community composition - Pool habitat
Measure	Fish community composition - Slackwater habitat
Measure	Fish community species composition
Measure	Macroinvertebrate functional feeding group abundance
Measure	Riparian Vegetation Composition
Measure	Riparian Wildlife Composition
Measure	Terrestrial Mammal Wildlife Composition
Measure	Trout Fishery - Presence-absence
Measure	Upland Vegetation Composition
Measure	Vegetation community species composition
Measure	Vegetation type
Measure	Wetland Vegetation Compostion
Statistic	Change in fish community composition - functional type
Statistic	Fish Community Composition - %
Statistic	Fish Community Composition - historical
Statistic	Fish Species Composition - %
Statistic	Macroinvertebrate community composition - % taxa
Statistic	Macroinvertebrate species richness
Statistic	Natural vegetation assemblage change
Statistic	Natural vegetation assemblage succession
Statistic	Recreational fishing effort - % of time
Statistic	Recreational fishing harvest - % of catch
Indicator	Canadian Ecological Flow Generalist Index
Indicator	Canadian Ecological Flow Specialist Index
Indicator	Change in fish community composition - equilibrium life histories
Indicator	Change in fish community composition - opportunistic life histories
Indicator	Change in fish community composition - periodic life histories
Indicator	Colwater Fisheries - Presence-absence
Indicator	Coolwater Fish Community Indicator
Indicator	Fish Community Composition - %
Indicator	Fish Community Health
Indicator	Fish Taxonomic Distinctiveness Index
Indicator	Fishery Resources Indicator
Indicator	Macroinvertebrate Community Health
Indicator	Riparian vegetation alteration
Indicator	Sportfishing Satisfaction Rating
Indicator	Tree Jaccard's coefficient of community similarity
Indicator	Tree Sorensen's Similarity Index
Indicator	Warmwater Fish Community Indicator

Frequencies based on EMH Catalog Contents as of January 31, 2017

3.7.8 BB_Genetics, mixing, metapopulation

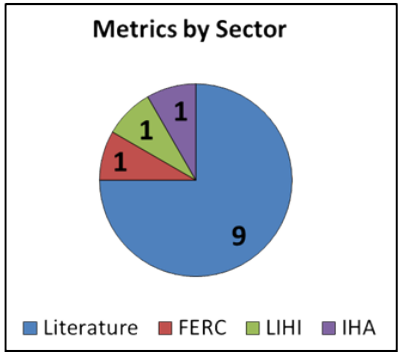
7

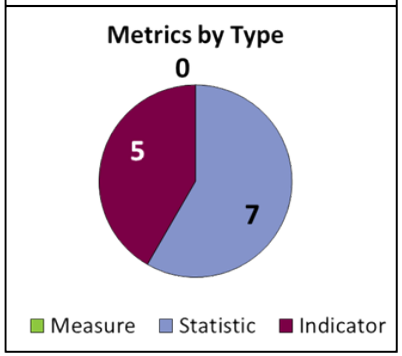
BB Biota and Biodiversity

BB_Genetics, mixing, metapopulation

Genetics and population mixing, including metapopulation dynamics

Sector	studies	metrics
IHA	4	1
LIHI	5	1
FERC	5	1
Peer-Reviewed Literature	247	9
Totals	261	12





Metric Type	Metric Name
Statistic	Genetic diversity - allelic richness
Statistic	Genetic diversity - heterozygosity
Statistic	Genetic diversity - inbreeding coeff
Statistic	Genetic diversity - population structure
Statistic	Proportion polymorphic loci
Indicator	Gene flow
Indicator	Genetic population mixing
Indicator	Morphological and genetic analyses of armored catfish
Indicator	Nei's genetic diversity

Frequencies based on EMH Catalog Contents as of January 31, 2017

3.7.9 BB_Habitat, critical habitat, or surrogates of such

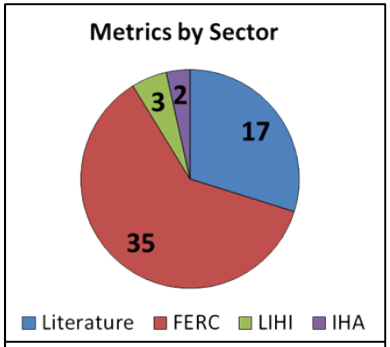
7

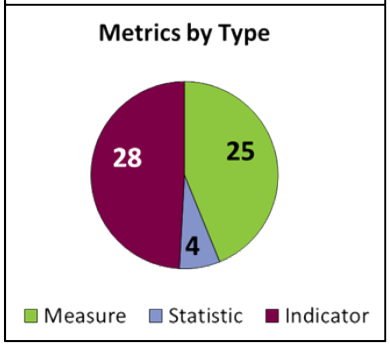
BB Biota and Biodiversity

BB_Habitat, critical habitat, or surrogates of such

Indices of habitat, area, suitability, and so on, for organisms

Sector	studies	metrics
IHA	4	2
LIHI	5	3
FERC	5	35
Peer-Reviewed Literature	247	17
Totals	261	57





Metric Type	Metric Name
Measure	Avian species nests/roosts
Measure	Critical Habitat - length
Measure	Critical Habitat - presence-absence
Measure	EFH - presence-absence
Measure	Emergent wetland area
Measure	Essential Fish Habitat - presence-absence
Measure	Fish distribution - area
Measure	Fish habitat characteristic 1 - cover
Measure	Fish spawning gravel volume
Measure	Goat habitat characteristic 1
Measure	Goat habitat characteristic 2
Measure	Plant habitat characteristics 1
Measure	Reservoir water depth
Measure	Shoreline habitat area
Measure	Stream mesohabitat area
Measure	Stream vegetation patch size
Measure	Upstream Diadromous Fish Habitat - presence-absence
Measure	Wetlant Habitat Type - categorical
Statistic	Inundated mesohabitat area - %
Statistic	Relationship fish density/ habitat type regulated site
Statistic	Relationship fish density/ habitat type unregulated site
Statistic	WQ-macroinvertebrate correlation
Indicator	Aquatic habitat diversity Indicator
Indicator	Aquatic Habitat Quality Indicator
Indicator	Baseline forest and plant diversity
Indicator	Canadian Ecological Flow Index
Indicator	Continuous monitoring of ecological indicators

Metric Type	Metric Name
Indicator	Deviation wetted habitat perimeter
Indicator	Fish spawning habitat Indicator
Indicator	Fish spawning habitat quality indicator
Indicator	Habitat Quality Indicator
Indicator	Habitat Suitability Index
Indicator	Hydrology-fish association correlation
Indicator	Instream habitat alteration
Indicator	Mussel habitat quality indicator
Indicator	RBA score
Indicator	Riparian habitat quality index
Indicator	Riparian Habitat Quality Indicator
Indicator	Stream Habitat Quality Indicator
Indicator	Stream vegetation habitat characteristic
Indicator	Terrestrial Wildlife Habitat Quality Indicator
Indicator	Weighted Useable Area
Indicator	Wetted habitat perimeter
Indicator	Wetted habitat perimeter breakpoint
Indicator	Years since construction

Frequencies based on EMH Catalog Contents as of January 31, 2017

3.7.10 BB_Internal composition nutrient abnormalities

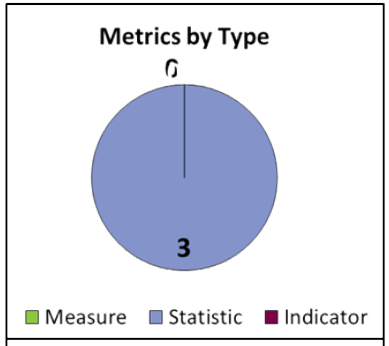
BB Biota and Biodiversity

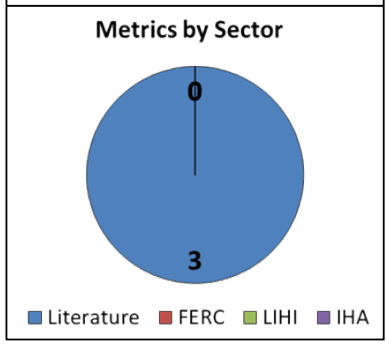
BB_Internal composition nutrient abnormalities

Nutritional composition and makeup of organisms, including elemental stoichiometry. It includes levels of internal homeostasis, as well as morphological, genetic, or hormonal abnormalities caused by contaminants

Sector	studies	metrics
IHA	4	0
LIHI	5	0
FERC	5	0
Peer-Reviewed Literature	247	3
Totals	261	3

Metric Type	Metric Name
Statistic	Nitrogen-to-carbon ratio in phytoplankton
Statistic	Oxygen-to-carbon ratio in phytoplankton
Statistic	Phosphorous-to-carbon ratio in phytoplankton





Frequencies based on EMH Catalog Contents as of January 31, 2017

3.7.11 BB_Internal composition nutrient abnormalities

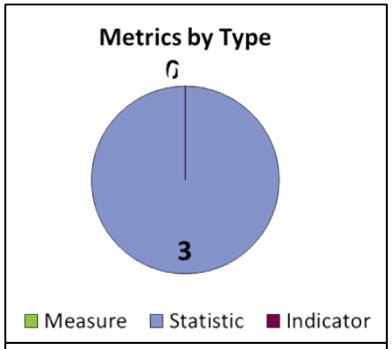
BB Biota and Biodiversity

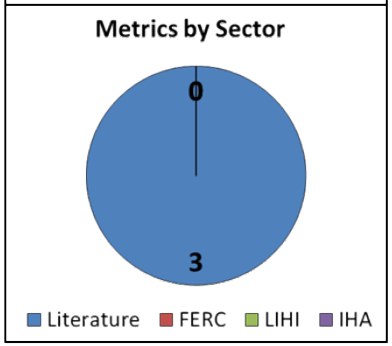
BB_Internal composition nutrient abnormalities

Nutritional composition and makeup of organisms, including elemental stoichiometry. It includes levels of internal homeostasis, as well as morphological, genetic, or hormonal abnormalities caused by contaminants

Sector	studies	metrics
IHA	4	0
LIHI	5	0
FERC	5	0
Peer-Reviewed Literature	247	3
Totals	261	3

Metric Type	Metric Name
Statistic	Nitrogen-to-carbon ratio in phytoplankton
Statistic	Oxygen-to-carbon ratio in phytoplankton
Statistic	Phosphorous-to-carbon ratio in phytoplankton





Frequencies based on EMH Catalog Contents as of January 31, 2017

3.7.12 BB_Life history trait characteristics

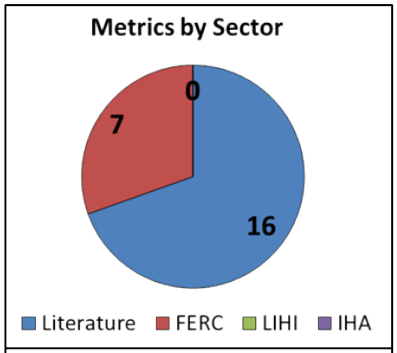
7

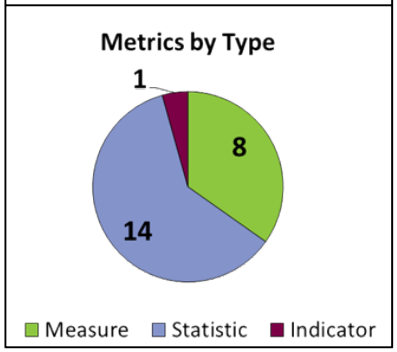
BB Biota and Biodiversity

BB_Life history trait characteristics

Life history trait characteristics and their values, such as duration of spawning, fecundity, reproductive mode (note that this category deals only with characteristics themselves and not the composition of the community. See Functional group, or species or trait composition)

Sector	studies	metrics
IHA	4	0
LIHI	5	0
FERC	5	7
Peer-Reviewed Literature	247	16
Totals	261	23





Metric Type	Metric Name
Measure	Fish life history characteristic - spawn 2
Measure	Fish morphology characteristic 1
Measure	Mussel life history characteristic 1
Measure	Non-native Mussel life history characteristic 2
Measure	Non-native Mussel life history characteristic 3
Statistic	Date downstream migration
Statistic	Date upstream migration
Statistic	Duration downstream migration
Statistic	Duration upstream migration
Statistic	Fish life history characteristic - early development (incubation rate)
Statistic	Fish life history characteristic - spawn 3
Statistic	Fish life history characteristic - spawn 4
Statistic	Fish life history characteristic - spawn duration
Statistic	Fish morphology characteristic 2
Indicator	Mussel-Host Fish Strength Indicator

Frequencies based on EMH Catalog Contents as of January 31, 2017

3.7.13 BB_Presence, absence, occupancy or detection

7

BB Biota and Biodiversity

Sector	studies	metrics
IHA	4	13
LIHI	5	19
FERC	5	22
Peer-Reviewed Literature	247	12
Totals	261	66

BB_Presence, absence, occupancy, or detection

Organism presence/absence in an area (including pseudo-absence), occupancy, and detection probability

Metric Type	Metric Name
Measure	Coldwater Fish - presence-absence
Measure	Diadromous fish - historical presence-absence
Measure	Diadromous fish - presence-absence
Measure	Federally listed species - presence-absence
Measure	Federally listed species of concern - presence-absence
Measure	Fish detection
Measure	Fish range
Measure	Fish species presence-absence
Measure	Goat distribution
Measure	Goat range
Measure	IEPP - presence-absence
Measure	Invasive macrophyte presence/absence
Measure	Native macrophyte presence/absence
Measure	Non-native fish - presence-absence
Measure	Non-native vegetation - presence-absence
Measure	Nusiance macrophyte presence-absence
Measure	Phytoplankton species presence-absence
Measure	River/Potadromous fish - presence-absence
Measure	Sensitive species - presence-absence
Measure	Sensitive vegetation species - presence-absence
Measure	Vegetation flowering - presence
Measure	Wetland Habitat - presence-absence

Metric Type	Metric Name
Statistic	Deer detection
Statistic	Deer distribution - patch occupancy
Indicator	Baseline aquatic flora and fauna
Indicator	Baseline survey of potentially impacted species
Indicator	Baseline terrestrial wildlife
Indicator	Identification of target species
Indicator	Identificaton of endangered, vulnerable & rare species
Indicator	Monitoring of biodiversity impacts
Indicator	Monitoring of biological trends
Indicator	Quarterly survey of terrestrial species
Indicator	Quarterly surveys of plankton, benthos and fish
Indicator	Rapid assessment of cumulative biodiversity impacts
Indicator	Special survey of key fish species
Indicator	Special surveys of key terrestrial species
Indicator	Transmission line impacts on biodiversity

Frequencies based on EMH Catalog Contents as of January 31, 2017

3.7.14 BB_Richness, diversity, evenness, or IBI types of measures

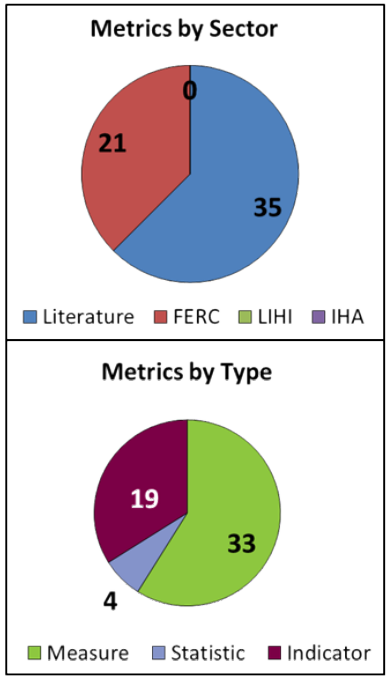
7

BB Biota and Biodiversity

BB_Richness, diversity, evenness, or IBI types of measures

Species richness, diversity, evenness, or indices-of-biotic-integrity metrics used to characterize one or more components of the biotic community

Sector	studies	metrics
IHA	4	0
LIHI	5	0
FERC	5	21
Peer-Reviewed Literature	247	35
Totals	261	56



Metric Type	Metric Name
Measure	Amphibian Species Richness
Measure	Aquatic Mammal Species Richness
Measure	Aquatic Reptile Species Richness
Measure	Bird Species Richness
Measure	Bufferly Species Richness
Measure	Fish species richness
Measure	Fish Species Richness - historical
Measure	IEPP - richness
Measure	Macroinvertebrate species richness
Measure	Macrophyte species richness
Measure	Mussel species richness
Measure	Phytoplankton species richness
Measure	Terrestrial Mammal Wildlife Species Mammal Richness
Measure	Warmwater Fish Species Richness
Measure	Wetland Vegetation Species Richness
Statistic	Fish species density
Statistic	Fish species richness
Statistic	Invasive macrophyte species richness
Statistic	Native macrophyte species richness
Indicator	Aquatic Resources Quality Indicator
Indicator	Diversity in the Environmental Indicator
Indicator	Ecological Benefit Indicator
Indicator	Ecological condition
Indicator	Macroinvertebrate Community Health
Indicator	Macroinvertebrate Pielou evenness
Indicator	Macroinvertebrate Shannon-Weiner diversity

Metric Type	Metric Name
Indicator	Phytoplankton Shannon-Wiener index
Indicator	Terrestrial Resources Quality Indicator
Indicator	Tree Berger-Parker Dominance Index
Indicator	Tree Beta diversity
Indicator	Tree Shannon-Weiner Diversity Index
Indicator	Tree Simpson's Evenness index
Indicator	Tree Simpson's Reciprocal Index
Indicator	Tree Species Dominance Index

Frequencies based on EMH Catalog Contents as of January 31, 2017

REFERENCES:

Hydropower Sustainability Assessment Protocol. November 2010 "Hydropower Sustainability Assessment Protocol"(220 page report) available at http://www.hydrosustainability.org/getattachment/7e212656-9d26-4ebc-96b8-1f27eaebc2ed/The-Hydropower-Sustainability-Assessment-Protocol.aspx

M.J. Sale, D. Hall, and J. Keil, 2016. Low Impact Hydropower Institute Certification Handbook, 2nd Edition. Low Impact Hydropower Institute, Harrington Park, NJ.

Pracheil, Brenda M., Ryan A. McManamay, Esther S. Parish, Shelaine L. Curd, Brennan T. Smith. June 2016. *Environmental Metrics for New Hydropower: Terminology and Categories* ORNL TM-2016/720.

Schramm, M. P, M. S Bevelhimer, and C. R DeRolph. 2016. A Synthesis Of Environmental And Recreational Mitigation Requirements At Hydropower Projects In The United States. Environmental Science And Policy: 87-96.

APPENDIXA. SYSTEMATIC REVIEW OF PEER-REVIEWED SCHOLARLY LITERATURE ON HYDROPOWER METRICS

Systematic review of peer-reviewed scholarly literature on hydropower metrics

Generation of search strings

This study employs a systematic review of scientific peer-review journal articles to summarize metrics that have been used to quantify the effects of hydropower. Systematic reviews set forth rigorous and repeatable study inclusion criteria and documentation (including stakeholder input, where appropriate) of search terms, search dates, and which studies were and were not included so that the body of literature discovered and included in the review is not only replicable, but is also unbiased with respect to point-of-view (CEE 2013). For example, one hydropower stakeholder conducting a systematic review may only choose a search string such as "hydropower impact" which suggests negative environmental consequences, whereas a different hydropower stakeholder may choose the search string "hydropower effect" which is impartial to the direction of change. While each of these search strings will likely discover some overlapping literature, it is also likely that there will be some peer-reviewed articles that appear in one search string and not the other. In this example, both search strings would be important to include because all stakeholder viewpoints are imperative for presenting an unbiased review and using search strings that discover all relevant bodies of literature are important. Therefore, obtaining stakeholder input on search strings is a critical component for obtaining an unbiased perspective of the literature.

Whenever possible, open-access or open-access compatible databases and tools were used to ensure transparency and availability to the entire stakeholder community with the understanding that many will not have access to proprietary search and reference management tools.
Also, although the importance and relevance of gray literature to hydropower regulatory decision making is recognized, it was excluded from the systematic review for three primary reasons. First, representing this body of literature in a consistent or representative way is difficult due to difficulties in securing and discovering texts. Second, reviewing gray literature presents a unique challenge compared to peer-review literature because peer-reviewed papers are, by definition, reviewed by other experts. Evaluation of the scientific rigor of gray literature can vary by the author/ authoring organization's policies and encompasses the spectrum from an equally or more rigorous process to that found in the peer-reindicview literature to no additional review. Third, a parallel review of hydropower regulation and certification documents will be ongoing as part of this project that will incorporate gray literature that has been used in hydropower decision-making. Furthermore, because gray literature included in hydropower regulation and certification documents has been scrutinized as part of the licensing or certification process, there is presumably some threshold of scientific rigor that has been surpassed.
Initial search strings (insert table of search strings) were obtained from discussion among four ORNL research staff with hydropower industry, hydropower environmental, and sustainability science expertise.

The intent of these discussions was to devise a list of search strings for the systematic review that would represent multiple stakeholder viewpoints and generate a comprehensive list of literature search results that was not overly duplicative, but still left as few gaps in overall search results as possible. These discussions resulted in the creation of 216 unique search strings containing one environmental term (e.g., "Land cover", biodiversity) and one hydropower term (e.g., dam, powerhouse). The "scientific categories" from the "Hydropower Environmental Terminology" paper produced as part of this project formed the basis for the environmental terms in addition to major biological groups and terms that ORNL staff thought would help yield unique and pertinent search results. Hydropower terms in search strings were named based on input from ORNL hydropower engineering staff. The Boolean term "OR" was used

in cases where multiple forms of words searching for the same thing were used in search strings (e.g., "Hydropower OR Hydroelectric") and asterisks were used to enable searching for multiple endings on words (e.g., "Fragment*" would search for "fragment, fragmented, fragments, fragmentation, fragmenting, etc.). Because some of the search strings were quite general and yielded large amounts of information that did not pertain to hydropower or environmental sciences, an initial screening of search strings was conducted using Google Scholar searches for each strings recording the number of results (CEE 2013). The titles of the first seven results (the number of search results that fit on the average screen) were then surveyed as an indicator of whether the string would provide useful results for this review by noting whether the results contained environmental information. If any one of the first seven results pertained to environmental effects in the title, the search string was categorized as containing information potentially useful for this project and was retained for further use. If search strings did not contain information potentially useful for this project, the search string was discarded. For instance, the search string "metric* dam*" (see Table 1 caption for explanation of asterisks and quotations in search strings) was discarded because all seven results were related to the field of particle physics. In total, 150 unique search strings were retained from the initial search screen. It is this list of 150 search strings that will be presented to stakeholders for input.

Study inclusion criteria

The final list of search strings was searched using Google Scholar during 9 September, 2016 through 22 September, 2016. The first 200 search results were screened for potential further inclusion in the review. All peer-review papers that contained mention of environmental characteristics at hydropower facilities in the paper title, abstract, or executive summary in addition to papers that contained terms that signaled potential relevance to this project were retained for further review. An example of the type of paper that signaled potential relevance to this project that was retained would be a paper that discussed watershed land use change over a period of time because hydropower development and reservoir inundation is sometimes calculated in land use change statistics. Likewise, papers that discussed the response of an organism or group of organisms to flow or river regulation were retained for further review even if hydropower was not specifically mentioned. Papers that were further included in the review were entered into Mendeley (https://www.mendeley.com)—an open access web-tool for managing references and PDFs of literature. Papers that could not be definitively included or excluded based on the title and abstract were also retained for further review. Papers not including information on the environmental effects of hydropower were excluded and a Mendeley folder was created to document the citations of peer-reviewed papers that were screened but not included in the catalog. In this way, interested parties can gain a better understanding of why a study was or was not included in the review.

Database creation

Papers retained were searched for metrics characterizing the environmental effects of hydropower as well as for other information relevant to the metric such as values, methods of data collection, and temporal resolution of the metric for incorporation into the catalog using data in tables, figures, and text of papers (Appendix A). Metrics were considered as any means, either quantitative or qualitative, of characterizing the environment at, near, or associated with a hydropower plant. The database of metrics was then georeferenced and related to the NHAAP or GRanD hydropower databases where possible to create a spatially-related database of

hydropower environmental characteristics. A bibliography of papers that passed the initial review filter but did not contain metrics relevant to this study are provided in Appendix B.

Catalog creation

To gain an understanding of what metrics have been most commonly used and most useful for describing the environmental effects of hydropower, a catalog indexed by metric was created. This catalog also contained summaries of metric usage including the number of times, locations, and studies that used each metric as well as a narrative description. Summarized metrics were also then coded with unique identifiers corresponding to metric type, category, and number.

Data analysis

All data analysis was conducted in R (Version 3.2.2, "Fire Safety"). A kappa statistic (κ) was calculated on a subset of 25% search results to quantify consistency in study inclusion between two article reviewers (ORNL staff Dr. Brenda Pracheil and Dr. Ryan McManamay), calculated as

$$\kappa=(p_o-p_e)/(1-p_e)$$

where p_o is the observed agreement of article inclusion among those rating articles and pe is the probability of random agreement between reviewers calculated from the data collected. Reviewers in complete agreement would yield a $\kappa=1$ and agreement no greater than that expected by random chance (p_e) would yield a $\kappa < 0$. A $\kappa > 0.50$ was required between a pair of reviewers before searches were concluded to be of sufficient consistency. The k-value between the two in this study was 0.86.

LITERATURE CITED

Collaboration for Environmental Evidence (CEE) (2013). Guidelines for systematic review and evidence synthesis in environmental management version 4.2. Environmental evidence: http://devtestsite.co.uk/cee/wp-content/uploads/ 2014/06/Review-guidelines-version-4.2-final.pdf

Table 1. Search terms forming initial search strings for systematic review. Each search string was comprised of one environmental term and one hydropower term. Quotations around compound terms such as “flow regime” or “stilling basin” were used to help restrict search results to those relevant to this review. Asterisks were used to include multiple forms of words. For example, “alter*” would search for “altered”, “alteration”, “alters”, etc.

Environmental Term	Hydropower Term
Alter*	Conveyance
Assess*	“Dam* OR Barrage*”
Biodiversity	“Hydropower OR Hydroelectric”
Biot*	Infrastructure
“Communit* OR Community”	Powerhouse
“Connect* OR Connectivity”	“Reservoir* OR Impound*”
Effect*	“Tailrace* OR Tailwater*”
Environment*	Turbine
Fish*	
Flow*	
"Flow regime*"	
“Fragment* OR Fragmentation”	
Geomorph*	
Impact*	
"Land cover"	
Limnolog*	
Macroinvert*	
Macrophyte*	
Measur*	
Metric*	
Mussel*	
Population	
Quantif*	
Sediment*	
Sustain*	
"Water quality"	
"Water quantity"	

APPENDIX B. BIBLIOGRAPY OF PEER-REVIEW LITERATURE INCLUDED IN THE DATABASE

Appendix B. Papers in systematic review classified as relevant to environmental effects of hydropower and had metrics that were included in the metric database and catalog. As of 10 January 10, 2017, there were 97 studies included in the database.

Agostinho, A. A., Pelicice, F. M., & Gomes, L. C. (2008). Dams and the fish fauna of the Neotropical region: impacts and management related to diversity and fisheries. *Brazilian Journal of Biology, 68*(4), 1119-1132.

Alonso-Gonzalez, C., & Gort??zar, J. a. (2008). Dam function rules based on brown trout flow requirements: Design of environmental flow regimes in regulated streams. *Hydrobiologia*, *609*(1), 253-262.

Anderson, E. P., & Pringle, C. M. (2008). Quantifying the extent of river fragmentation by hydropower dams in the Sarapiqui River Basin, Costa Rica. *Aquatic Conservation: Marine and Freshwater Ecosystems, 18*(4), 408--417.

Andriolo, A., Piovezan, U., Costa, M. J. R., Torres, H. A., Vogliotti, A., Zerbini, A. N., & Duarte, J. M. B. (2013). Severe population decline of marsh deer, Blastocerus dichotomus (Cetartiodactyla: Cervidae), a threatened species, caused by flooding related to a hydroelectric power plant. *Zoologia, 30*(6), 630-638.

Arias, M. E., Cochrane, T. A., Lawrence, K. S., Killeen, T. J., & Farrell, T. A. (2011). Paying the forest for electricity: a modelling framework to market forest conservation as payment for ecosystem services benefiting hydropower generation. *Environmental Conservation*, *38*(04), 473-484.

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Bambace, L. A. W., Ramos, F. M., Lima, I. B. T., & Rosa, R. R. (2007). Mitigation and recovery of methane emissions from tropical hydroelectric dams. *Energy, 32*(6), 1038-1046.

Bardossy, A., & Molnr, Z. (2004). Statistical and geostatistical investigations into the effects of the Gabcikovo hydropower plant on the groundwater resources of northwest Hungary/Analyses. *Hydrological Sciences Journal, 49*(4), 623.

Bartholow, J. M., Campbell, S. G., & Flug, M. (2004). Predicting the thermal effects of dam removal on the Klamath River. *Environmental Management, 34*(6), 8856-8874.

Bastien, J., Demarty, M., & Tremblay, A. (2011). CO2 and CH4 diffusive and degassing fluxes from 2003 to 2009 at Eastmain 1 reservoir, Qu \' e bec, Canada. *Inland Waters, 1*(2), 113-123.

Bates, J. M. (1962). The impact of impoundment on the mussel fauna of Kentucky Reservoir, Tennessee River. *American Midland Naturalist, 68*(1), 232-236.

Beamesderfer, R. C., & Rieman, B. E. (1990). Management implications of a model of predation by a resident fish on juvenile salmonids migrating through a Columbia River reservoir. *North American Journal of Fisheries Managemen, 10*(3), 290-304.

Beghelli, F. G. S., Santos, A. C. A., & Urso-Guimares, M. V. (2012). Relationship between space distribution of the benthic macroinvertebrates community and trophic state in a Neotropical reservoir (Itupararanga, Brazil). *Biota, 12*(4), 114-124.

Beilfuss, R. (2010). Modelling trade-offs between hydropower generation and environmental flow scenarios: a case study of the Lower Zambezi River Basin, Mozambique. *International Journal of River Basin Management, 8*(3-4), 331-347.

Bell, L. M. (1985). A Fish Passage Problem at the Seton Hydroelectric Project in Southwestern British Columbia. *Canadian Water Resources Journal, 10*(1), 32-39.

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APPENDIX C. SUMMARY OF STUDY LOCATIONS AND ENVIRONMENTAL METRIC CATEGORIES EXTRACTED FROM THE 97 PEER-REVIEWED JOURNAL ARTICLES

Reference Article	Continent	Country (or countries)	Dam(s) or Study Location	River(s)	Metrics	Categories
Agostinho_etAl_2008 [23]	S. America	Brazil, Paraguay	Tres Irmaos, Corumba, Itaipu, and Porto Primavera Dams	Corumba, Parana, Tiete, Parana Yacyreta, Parana	4	BB
AlonsoGonzalez_etAl_2008 [24]	Europe	Spain	Proposed dam	Tormes	26	BB, W1
Anderson_et_al_2008 [25]	S. America	Costa Rica	Suerkata, Toro I, Toro II, Volcan, Segundo, El Angel, Dona Julia, Cariblanco, and Don Pedro Dams	Sarapiqui, Toro, Volcan, Agnel, Tuolumne	9	W1
Andriolo_etAl_2013 [26]	S. America	Brazil	Porto Primovera Dam	Paraná	4	BB
Arias_etAl_2011 [27]	Asia	Cambodia	Proposed dam	Mekong	6	GM, LC
Armanini_etAl_2014 [28]	N. America	Canada	Steephill Falls Generating Station	Magpie, Batchawana	3	BB
Arnekleiv_etAl_2007 [29]	Europe	Norway	Mjosa Dam	Gudbrandsdalslågen	5	BB, W1, W2
Bacheler_etAl_2004 [30]	N. America	United States	Carite Dam	La Plata	4	BB
Bain_etAl_1988 [31]	N. America	United States	Stream reach flow modified by four dams (no names provided)	Connecticut	12	BB, GM
Bambace_etal_2007 [32]	S. America	Brazil	Serra da Mesa and Tucurui Dams	Toncatins	3	W1
Bardossy_etal_2004 [33]	Europe	Slovakia	Gabicikovo Dam	Danube	18	W1
Bartholow_etal_2004 [34]	N. America	United States	Iron Gate, John C. Boyle, Keno, and Copco Dams	Klamath	20	W1
Bastien_etAl_2011 [35]	N. America	Canada	Sarcelle Dam	Eastmain	4	W2
Bates_1962 [36]	N. America	United States	Kentucky Dam	Tennessee	2	BB

Beamesderfer_et_al_1990 [37]	N. America	United States	John Day Dam	Columbia	22	W1
Beghelli_et Al_2012 [38]	S. America	Brazil	Itupararanga Dam	Sorocaba	9	BB, W2
Beilfuss_et_al_1994 [39]	Oceania	Australia	Windamere Dam	Cudgegong	12	W1
Bell_1985 [40]	N. America	Canada	Seton Dam	Seton	2	W1
Benchimol_et_al_2014 [41]	S. America	Brazil	Balbina Dam	Uatuma	6	W1
Benejam_et Al_2016 [42]	Europe	Spain	Sixteen small hydropower plants: Brutau 1, Brutau 2, Pardines, El Molí Rialp, Feitús, Cruanyes, Molí de Sart, Matabosch, Montagut, Molí Gran Pont Vell, Cal Gat, Surribes, L'Escala, La Cubia, Fàbrica Tomàs, Crous	Upper Ter	9	BB, GM
Benjankar_etAl_2012 [42]	N. America	United States	Libby Dam	Kootenai	3	BB, W1
Benn_et_al_1994 [43]	Africa	Zambia, Zimbabwe, Mozambique	Kariba, Kafue George, and Cahora Bassa Dams	Zambezi, Kafue	9	W1
BennettAndKeevil_2010 [44]	N. America	Canada	Trent-Severn Waterway locks and dams	Trent-Severn Waterway	1	BB
Bergman_et_al_2014 [45]	Asia	Israel	Nahal Oz Dam	Nahal Yare'akh River	9	W1
Berkes_1982 [46]	N. America	Canada	La Grande 1 Dam	La Grande	5	BB
Bhatt_and_Khanal_2010 [47]	Asia	Nepal	Indrawati III Dam	Indrawati	15	W1, W2
Bhatt_et_al_2011 [48]	Asia	Nepal	Upper Bhotekoshi Hydropower Project	Bhotekoshi	19	W1
BhattAndKhanal_2012 [49]	Asia	Nepal	Upper Bhotekoshi Hydropower Project	Bhotekoshi	18	W1, W2
Bhutiani_et Al_2014 [50]	Asia	India	Tehri Dam	Bhagirathi	20	W2

Bini_etAl_1999 [51]	S. America	Paraguay	Itaipu Dam	Parana Yacyreta	13	BB, W1
Black_et_al_2005 [52]	Europe	Scotland	Megget Dam	Allt a' Chireachain, Megget	333	BB, CF, GM, ID, LC, W1, W2
Bond_et_al_1978 [53]	Africa	Mozambique	Cahora Bassa Dam	Zambezi	53	BB, GM, ID, LC, W1, W2
Branco_etAl_2012 [54]	Europe	Portugal	A total of 196 stream sampling sites in three river basins.	Tagus, Mondego, Vouga	27	BB, CF, GM, ID, W1, W2
Bravard_et_al_1999 [55]	Europe	France	River reaches (no named dams)	Rhone, Drôme, Drac, Ain	6	CF, GM, W1
Budhu_et_al_1994 [56]	N. America	United States	Glen Canyon Dam	Colorado	5	GM, W1
Calles_et_al_2013 [57]	Europe	Sweden	Ätrafors HEP	Atran	6	BB, W1
Callisto_et_al_2005 [58]	S. America	Brazil	Paulo Afonso, Xingo, and Moxoto Dams	Sao Francisco	22	BB, W1, W2
Carley_et_al_2012 [59]	N. America	United States	Daguerre Point and Harry L. Englebright Dams	Yuba	12	GM, W1
Chicharo_et_al_2006 [60]	Europe	Portugal	Alqueva Dam	Guadiana	23	BB, W1, W2
Chiu_et_al_2013 [61]	Asia	Taiwan	Unnamed dam	Dajia	7	BB, GM
Churchill_2013 [62]	N. America	United States	Denison Dam	Red	21	BB, W1, W2
Craven_et_al_2010 [63]	N. America	United States	Flint River and R L Harris Dams	Flint, Tallapoosa	44	BB, W1
Dai_et_al_2011 [64]	Asia	China	Three Gorges Dam	Yangtze	12	W1, W2
Dauble_1986 [65]	N. America	United States	Priest Rapids Dam	Columbia	7	BB, CF, W2

de_Almeida_etal_2005 [66]	Europe	Portugal	Fourteen hydropower plants: Ribeiradio, Sr.a do Monforte, Alvito, Pêro Martins, Atalaia, Asse-Dasse, Castelo de Paiva, Castro Daire, Póvoa, Midões, Alvarenga, Pinhosão, Portela, and Girabolhos	Vouga, Côa, Ocreza, Mondego, Paiva	2	W1
deAlmeida_et_al_2003 [67]	S. America	Brazil	Barra Bonita, Ibitinga, Mario Lopes Leao, Tres Irmaos, Taquarucu, Nova Avanhadava, Rosana, Capivara, and Bairi Dams	Tiete, Paranapema	3	BB
Dean_and_Schmidt_2013 [68]	N. America	United States	Caballo, Elephant Butte, Luis L. Leon, La Boquilla, and Francisco I. Madera Dams	Rio Grande, Rio Conchos	10	GM, W1
Duchemin_et_al_1995 [69]	N. America	Canada	Laforge 1 and La Grande 2 Dams	LaForge, La Grande	20	W1, W2
Ebel_1969 [70]	N. America	United States	Priest Rapids, McNary, Ice Harbor, Grand Coulee, Bonneville, Chief Joseph, The Dalles, Wanupum, Rocky Reach, and Rock Island Dams	Columbia, Snake,	18	BB, CF, W1, W2
Effler_et_al_1988 [71]	N. America	United States	Cannonsville Dam	Delaware	25	W2
Englund_et_al_2008 [72]	Europe	Sweden	Mallengan	Lillian	16	BB, LC, W2
FosterAndRahs_1985 [73]	N. America	Canada	Proposed dam	Stikine	9	BB
Frobrich_et_al_2007 [74]	Asia	Turkemenistan	Kaparas Dam	Amu Darya	10	W1, W2
Gailbraith_and_Vaughn_2009 [75]	N. America	United States	Pine Creek and Broken Bow Dams	Little, Mountain Fork	13	BB, W1
Gain_et_al_2013 [76]	Asia	Tibet	Zangmu Dam	Brahmaputra	28	W1

Galbraith_et_al_2015 [77]	N. America	United States	Parr Shoals, Upper Androscoggin, William O'Huske Lock and Dam, New Savannah Bluff Lock and Dam, Adam T. Bower Memorial (inflatable) Dam, Amoskeag, Falls Village, Holts Pond Dam, Holyoke, Sinclair, Lloyd Shoals, Tillery, Oxford, Santee, Tar River Reservoir Dam, John H. Kerr	Broad, Androscoggin, Cape Fear, Savannah, Susquehanna, Merrimack, Housatonic, Neuse, Connecticut, Oconee, Ocmulgee, Pee Dee, Catawba, Santee, Tar, Roanoke	9	BB, W1
Gelwick_and_Mathews_1990 [78]	N. America	United States	Denison Dam	Red River	15	BB, W1, W2
Gobo_etAl_2014 [79]	Africa	Nigeria	Kainji Dam	Kainji	5	BB, GM, W1
Graf_2006 [80]	N. America	United States	Albeni Falls, Beaver, Blakely Mountain, Buford, Center Hill, Coolidge, Dnison, Douglas, Eufaula, Flaming Gorge, Folsom, Fontana, Grand Coulee, Greers Ferry, Hartwell, Hungry Horse, John H. Kerr, Keystone, Kinzua, Monticello, Navajo, Norfork, Norris, Oologah Lake, Owyhee, Palisades, Pine Flat, Sam Rayburn, Sanford, Sardis, Shasta, Tenkiller Ferry, Tiber, Tuttle Creek, Whitney, and Wright Patman Dams	Allegheny, American, Angelina, Arkansas, Big Blue, Brazos, Canadian, Caney Fork, Chattahoochee, Clinch, Columbia, Flathead, French Broad, Gila, Green, Illinois, Kings, Little Red, Little Tallahatchie, Little Tennessee, Marias,	52	GM, W1

				North Fork of the White, Ouachita, Owyhee, Pend Oreille, Putah Creek, Red River, Roanoke, Sacramento, San Juan, Savannah, Snake, Sulphur, Verdigris, White		
Grill_et_al_2014 [81]	Asia	China	Multiple existing and proposed dams	Mekong	132	CF, W1
Guo_etAl_2000 [82]	Asia	Indonesia	Wadaslintang Dam	Lunto	8	GM, ID, LC, W1
Hay_et_al_2008 [83]	N. America	United States	Gavins Point and Fort Randall Dams	Missouri	33	BB, W1, W2
Heidari_et_al_2013 [84]	Asia	Iran	Tarik Dam	Sefid-Rud	4	BB
Hughes_et_al_2011 [85]	N. America	United States	Bonneville Dam	Columbia	8	ID, W1
Humborg_et Al_2006 [86]	Europe	Sweden	Baltic Sea catchment	Vistula, Daugava, Oder	21	CF, GM, LC, W1, W2
Huo_etAl_2015 [87]	Asia	China	Xiangjiaba Dam	Jinsha	18	W2
Huraut_et_al_2002 [88]	Asia	Philippines	Ambuklao Dam	Agno	5	GM
Istvanovics_etAl_2010 [89]	Europe	Hungary	Tisza Dam	Tisza	17	BB, W1, W2
Jepsen_et_al_1998 [90]	Europe	Denmark	Tange Dam	Gudenå	2	BB
Jones_etAl_2014 [91]	N. America	United States	Norris Dam	Clinch	7	BB, GM
KasterAndJacobi_1978 [92]	N. America	United States	Eau Pleine Dam	Big Eau Pleine	2	BB, W1
Kemenes_et	S. America	Brazil	Balbina Dam	Uatuma	3	W2

Al_2007 [93]						
Klaver_et_al_2007 [94]	Europe	Romania, Serbia, Slovakia	Iron Gate II and Gabicikovo Dams	Danube	516	GM, W1, W2
Kotut_etAl_1998 [95]	Africa	Kenya	Turkwel Dam	Turkwel	4	BB
KumarAndSharma_2016 [96]	Asia	India	Koteshwar Dam	Bhagirathi	7	GM, LC, W1, W2
Laine_etAl_1998 [97]	Europe	Finland	Isohaara Dam	Kemijoki	8	BB, GM, ID, W1, W2
Larinier_2008 [98]	Europe	France	77 small-scale hydro dams in clusters along 7 rivers	Gave d'Oloron, Corrèze, Vézère, Salat, Gave de Pau, Neste, Saison	6	BB
Lehman_2011 [99]	N. America	United States	Ford Lake Dam	Huron	34	W1, W2
Ma_et_al_2016 [99]	Asia	China	Ertan Dam	Yalong Jiang	2	W1, W2
Malini_and_Rao_2014 [100]	Asia	India	Gangapur Dam	Godavari	6	GM
Meile_et_al_2011 [101]	Europe	Switzerland	Chippis, Vouvray, Steg, Stalden, Salanfe, Barberine, Ackersand, Bitsch, Mauvoisin, and Grand Dixence Dams	Navisence, Rhone, Vispa, Salanfe, Barbarine	6	W1
Miloskovic_et_al_2013 [102]	Europe	Serbia	Gruza Dam	Gruza	28	BB, W2
Mims_et_al_2013 [103]	N. America	United States	McCloud, Glen Ferris, Dillon, Mohawk, Morrow Point, Ridgeway, Trenton, Wanship, Yellowtail, and Delaware Dams	McCloud, Kanawha, Licking, Wlhonding, Gunnison, Uncompahgre, Republican, Weber, Bighorn, Olentangy	31	BB, CF, ID, W1
Mistak_etAl	N. America	United	Stronach Dam	Pine	57	BB,

_2003 [104]		States				GM, W2
Muir_et_al_2001 [105]	N. America	United States	Lower Granite, Lower Monumental, and McNary Dams	Snake, Columbia	7	BB, W1
Politano_et Al_2012 [106]	N. America	United States	Wells Dam	Columbia	2	W2
Ribi_etAl_2014 [107]	Europe	Switzerland	Maigrauge Dam	Sarine	4	BB, ID, W2
Ribolli_etAl_2012 [108]	S. America	Brazil	Machadinho Dam	Pelotas	7	BB
Scruton_etAl_2005 [109]	N. America	Canada	West Salmon Dam	West Salmon	8	BB, GM, W1, W2
Smith_etAl_2016 [110]	N. America	Canada	E.B. Campbell Dam	Saskatchewan	6	GM
Soltani_et_al_2010 [111]	Asia	Iran	15-Khordad Dam	Ghomrud	11	ID, LC, W1, W2
Song_et_al_2015 [112]	Asia	China	Three Gorges Dam	Yangtze	8	GM, W1
Stevens_etAl_1995 [113]	N. America	United States	Glen Canyon Dam	Colorado	7	BB, GM, LC
Tamene_et_al_2006 [114]	Africa	Ethiopia	Group of micro dams for supplemental household irrigation.	Tekeze River Basin	18	GM, ID, LC, W1
Thomaz_et Al_2009 [115]	S. America	Paraguay	Itaipu Dam	Parana Yacyreta	7	BB, W2
Thompson_etAl_2011 [116]	N. America	United States	Camino Dam	Silver Creek	13	BB, GM, W1, W2
Tufford_et_al_1999 [117]	N. America	United States	Santee Dam	Santee	37	BB, W1, W2

APPENDIX D. BIBLIOGRAPHY OF PEER-REVIEW LITERATURE THAT PASSED THE INITIAL REVIEW FILTER BUT WAS NOT INCLUDED IN THE DATABASE

Appendix C. Papers in systematic review classified as relevant to environmental effects of hydropower and did not have metrics to be included in the metric database and catalog.As of 10 January 10, 2017, there were 148 studies that were reviewed but did not contain metrics.

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