Instruction Manual: River Function Questionnaire



Approved for public release. Distribution is unlimited Ryan A. McManamay Brenda M. Pracheil Shelaine L. Curd Brennan T. Smith Esther Parish Adam Witt Anna West Kelsey Rugani Christopher R. DeRolph Mary Beth Day

May 2019



MANAGED BY UT-BATTELLE FOR THE US DEPARTMENT OF ENERGY

DOCUMENT AVAILABILITY

Reports produced after January 1, 1996, are generally available free via US Department of Energy (DOE) SciTech Connect.

Website www.osti.gov

Reports produced before January 1, 1996, may be purchased by members of the public from the following source:

National Technical Information Service 5285 Port Royal Road Springfield, VA 22161 *Telephone* 703-605-6000 (1-800-553-6847) *TDD* 703-487-4639 *Fax* 703-605-6900 *E-mail* info@ntis.gov *Website* http://classic.ntis.gov/

Reports are available to DOE employees, DOE contractors, Energy Technology Data Exchange representatives, and International Nuclear Information System representatives from the following source:

Office of Scientific and Technical Information PO Box 62 Oak Ridge, TN 37831 *Telephone* 865-576-8401 *Fax* 865-576-5728 *E-mail* reports@osti.gov *Website* http://www.osti.gov/contact.html

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

ORNL/TM-2019/1184

Environmental Science Division

INSTRUCTION MANUAL: RIVER FUNCTION QUESTIONNAIRE

Ryan A. McManamay Brenda M. Pracheil Shelaine L. Curd Brennan T. Smith Esther Parish Adam Witt Anna West Kelsey Rugani Christopher R. DeRolph Mary Beth Day

May 2019

Prepared by OAK RIDGE NATIONAL LABORATORY Oak Ridge, TN 37831-6283 managed by UT-BATTELLE, LLC for the US DEPARTMENT OF ENERGY under contract DE-AC05-00OR22725

CONTENTS

LIST	OF FIGURES	v
LIST	OF TABLES	v
1.	THE RIVER FUNCTION QUESTIONNAIRE	1
	1.1 BACKGROUND	1
	1.2 HOW IT WAS DEVELOPED	1
2.	GENERAL GUIDANCE FOR USE	2
3.	INSTRUCTIONS FOR USE	6
	3.1.1 Navigating the Questionnaire	6
	3.1.2 Completing the Questionnaire	7
	3.1.3 Interpreting the Questionnaire Output	10
4.	QUESTIONNAIRE CROSS-CUT WITH REGULATORY CRITERIA	17
	4.1 BACKGROUND	17
	4.1.1 § 5.9 (b.1) and § 5.11 (d.1)	17
	4.1.2 § 5.9 (b.4) and § 5.11 (d.3)	18
5.	ACKNOWLEDGEMENTS	19
6.	REFERENCES	19

LIST OF FIGURES

Figure 2.1. Instruction spreadsheet providing an overview of background, purpose, and general	
insructions for use.	7
Figure 2.2. Questionnaire spreadsheet.	8
Figure 2.3. (A) Inset displays the response to questions provided by a drop-down list.	8
Figure 2.4. Section of questionnaire for determining whether specific taxa (columns) apply to	
each question.	9
Figure 2.5. At the bottom of the questionnaire, there is a navigation button (red circle) that takes	
user to the tabular summary.	9
Figure 2.6. Summary spreasheet.	10
Figure 2.7. Top of Bar_plot spreadsheet with navigation buttons and first two bar plots	10
Figure 2.8. Bar plot depicting the percentage of "yes", "no", and "uncertain" responses relevant to	
each of the river functions	12
Figure 2.9. Bar plot depicting the percentage of "yes" responses that were relevant to specific	
spatial scales and a given river function.	13
Figure 2.10. Bar plot depicting the percentage of "yes" responses that were relevant to specific	1.4
taxa and a given river function.	14
Figure 2.11. Spider diagram depicting the proportion of questions answered "Yes" for each river	
function.	15
Figure 2.12. Spider diagram spreadsheet provides navigational buttons (to navigate to other	
sheets) and provides convenient print buttons to print the diagram or the river function	
summary table to .pdf.	16

LIST OF TABLES

Table 2.1. River functions and their descriptions used as indicators of the effects of hydropower	
on the river environment. From Pracheil et al. (in review).	2

1. THE RIVER FUNCTION QUESTIONNAIRE

1.1 BACKGROUND

The regulatory process for US hydropower is time- and resource-intensive to all involved. For instance, licensing new facilities or relicensing existing facilities, including pre-negotiation procedures, may take in excess of 15 years. This process typically involves evaluating project effects through a scoping and study implementation process. While some studies are critical to understanding project effects, certain studies may be unnecessary if they do not directly connect with potential project effects.

Part of the attempt of determining environmental issues is defining what constitutes "the environment" effected by hydropower development and operations. In a recent literature review and meta-analysis on global hydropower-environmental studies, Parish et al. (2019) assembled a meta-analysis and database representing the "universe" of potential environmental metrics used to measure the effects of hydropower on river environments (completed Fiscal Year (FY) 2018). Subsequently, Pracheil et al. (in review) categorized these metrics into 51 non-reducible river functions, which represent the dimensions of the hydropower-river environment. These functions provide a template to reduce complexity by organizing environmental effects into a series of indicator groups.

The River Function Questionnaire (Questionnaire) is a series of questions designed to help stakeholders determine the impacts of hydropower on river functions as outlined in Pracheil et al. (in review; Table 2.1) that may need to be understood or addressed through additional field studies or environmental assessments. In order to provide a platform accessible to many users, we developed the questionnaire in Microsoft Excel with convenient macro-enabled interactive features, such as print and navigation buttons. The Questionnaire was developed under the Department of Energy (DOE)-funded Environmental Metrics for Hydropower (EMH) project in FY 2018. The Questionnaire was iteratively reviewed by a 25-member advisory Board comprised of federal and state agencies, environmental non-governmental organizations, utility and developer interests, tribes, and scientists. After each review, the Questionnaire was subsequently updated to incorporate Board member comments.

The Questionnaire was designed with the expectation that individuals familiar with the specific river system and facility, preferably natural resource experts, would complete the questions. Ideally, Questionnaire users should also have some familiarity with major concepts in river ecology (e.g., River Continuum Concept, Vannote et al. 1980; Natural Flow Regime, Poff et al. 1997; Indicators of Hydrologic Alteration, Richter et al. 1996) and the environmental effects of hydropower. Individuals filling out the Questionnaire will likely be environmental consultants as an early-stage assessment, or resource agencies and NGOs familiar with the system or having years of experience working with the system.

1.2 HOW IT WAS DEVELOPED

ORNL assembled an initial compilation of 425 journal articles and reports from previous projects and reviews related to environmental effects of hydropower, including: environmental indicators for hydropower sustainability (Parish et al. 2019), future hydropower planning, siting, and landscape considerations (McManamay et al. 2015b); environmental flows, habitat fragmentation, and geomorphic considerations (McManamay 2014; McManamay et al. 2010, 2012, 2013a, 2015a; 2016a), meta-analyses of hydrologic alterations from dams (Poff and Zimmerman 2010; McManamay et al. 2013b), types of dams and hydropower operations (Poff and Hart 2002; McManamay et al. 2016b), and effects of dams on water quality (Olden et al. 2010). We then selected literature pertaining to each river function individually with the objective of identifying generalized effects of dams on each function and what factors could serve as predictors or indicators of those effects.

Each of the questions are considered "generic" to identify common environmental effects of hydropower and dams on river functions and are accompanied by a scientific reference to scientifically justify inclusion of the question. Questions were determined through scientific literature review and the direction of effect is based on outcomes of consensus among multiple sources (See "Bibliography" in Questionnaire). While it is recognized that dams and specific rivers are complex and inherently contextspecific, there is much scientific literature that suggests that some environmental responses are generic to dams, given certain properties of the structure and the river. For example, a diversion-bypass that dewaters a stream is likely to result in riparian encroachment on the stream channel. As another example, a dam that discharges water from the hypolimnion of a thermally stratified reservoir is likely to result in lower temperatures than would normally be expected. In these cases, the phenomena above lead to more evidence for evaluating the "Stream Channel" and "Water Temperature" river functions, respectively.

Each question pertains to at least one river function but may pertain to multiple river functions. On average, there are five questions supporting each river function, but the number of questions per function may range from four to eight. All questions must be answered "yes", "no", "uncertain", or "not applicable". Based on all answers, the total "yes", "no", and "uncertain" responses for a given river function are totaled and provided in a final summary table and graphs.

Questions were framed using an eco-evidence approach (Norris et al. 2012) and should be answered using existing information. All questions are structured in such a way that "yes" answers lead towards more evidence for a given river function being potentially impacted by a project or that might require further consideration. Questions answered "uncertain" also provide evidence of river functions where more information or data is needed. The questions (and associated river functions) are also organized by spatial scale (Basin, Project, Reservoir, and Downstream) and according to which types of taxa (e.g., fish, amphibian, bird, etc.) may be relevant. The spatial scale is automatically built into the Questionnaire, but users can specify which taxa are relevant to a given question by answering "yes" under each taxa column. These results are also summarized in the summary table.

An internal database keeps track of all responses, spatial scale relevance, taxa-relevance, and the river functions applicable to all responses. The Questionnaire automatically summarizes the number of questions answered "yes", "no", or "uncertain" responses according to river function. These summaries are provided in tabular and graphical form for users to evaluate evidence (from 0 to 1) for any river function.

2. GENERAL GUIDANCE FOR USE

The River Function Questionnaire is one component of the Environmental Decision Support (EDS) Toolkit and was created to help foster dialog among stakeholders and to focus discussions about the study needs of a given hydropower project. However, the Toolkit does not recommend or suggest mitigation actions or study methodology. For example, the Questionnaire may foster discussions regarding what environmental conditions are uncertain or where existing information is available or needed to address a given environmental issue (i.e., river function). The Questionnaire can be used at any stage of the FERC licensing procedure, but its most suitable application was envisioned for early in the regulatory process as project details and potential impacts are starting to be assessed.

Thus, used of the Toolkit may include (but not limited to):

1) hydropower applicants in identifying potential environmental issues within the Pre-Application Document (PAD) or Stage 1 Consultation

- 2) environmental stakeholders in identifying knowledge gaps and environmental concerns needing to be addressed through studies or mitigation, and/or
- 3) all stakeholders within scoping phases discussing what environmental issues need to be addressed.

All questions must be answered "yes", "no", "uncertain", or "not applicable". Furthermore, to affirmatively answer a question as "yes" or "no", some form of existing information must be provided (e.g., data, analysis, picture, literature, website, stream gage reading, etc). Questions were written so that "yes" answers provide more evidence of an affected river function, questions answered "uncertain" also provide an indication of where more information or data is needed. If questions cannot be answered "yes" or "no" confidently and with evidence, questions should be answered as "uncertain" or "not applicable". In some cases, questions may not be relevant to the project such as in cases where a resource does not exist at a facility or when an impact to a river function may be caused by an already existing alteration. For instance, environmental assessments evaluating the addition of hydropower to existing non-powered dams typically only consider the environmental effects of adding electrical generation infrastructure (e.g., turbines, penstocks, powerhouse) and not the pre-existing effects of the dam and reservoir. In these cases, answers to questions targeting dam development, in general, might be answered "not applicable".

Function Level	Code	River Function Name	River Function Description			
Biota and	F1	Abundance, density	Count or other measures of organisms per area			
Biodiversity	F51	Algae/ primary productivity (BB)	Algal blooms which lead to oxygen depletion and eutrophication			
	F5	Behavior, movement, colonization, extinction	Behavior of organisms in study area, including colonization, movement patterns, distance, duration, timing, frequency and/or extinction.			
	F6	Demographics, age, sex, size	Population demographics, including age, sex, and size			
	F7	Fitness, survival, growth, condition, reproduction, mortality	Fitness, survival, growth, condition, reproduction, or mortality of organisms			
	F8	Functional group, or species or trait composition	Grouping of organisms by functional or trait status, percentage composition			

 Table 2.1. River functions and their descriptions used as indicators of the effects of hydropower on the river environment. From Pracheil et al. (in review).

Function Level	Code	River Function Name	River Function Description				
	F9	Genetics, mixing, metapopulation	Genetics and population mixing, including metapopulation dynamics				
	F10	Habitat, critical habitat, or surrogates of such	Indices of habitat, area, suitability, and so on, for organisms				
	F11	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				
	F2	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.)				
	F3	Presence, absence, occupancy, or detection	Organism presence/absence in an area (including pseudo- absence), occupancy, and detection probability				
	F4	Species diversity	Species richness, diversity, evenness, or indices-of-biotic- integrity metrics used to characterize one or more components of the biotic community				
Water Quality	F40	Algae/ primary productivity (WQ)	Algal concentration including measures of primary productivity such as chlorophyll A or cyanotoxin.				
	F41	Buffering capacity	Characteristics including pH, alkalinity				
	F42	Dissolved gasses	Concentration of non-greenhouse gases in water				
	F43	Dissolved oxygen	Dissolved oxygen in water				
	F44	Ecosystem function	Ecosystem vital rates and processes, including gross primary productivity, respiration, biochemical oxygen demand				
	F45	Gas emissions	Concentration and ebullution of water-origin greenhouse gases				
	F46	Key elements	Elements and compounds that are not listed on the EPA Toxic and Priority Pollutants list				
	F47	Macromolecular pollutants	Pollutants listed on the EPA Toxic and Priority Pollutants list that are not included in other EMH categories				
	F48	Nutrients and organic material (C, N, P)	Dissolved organic carbon and other organic non-pollutants essential to life, including nitrogen, phosphorous, and inorganic carbon.				
	F49	Solid transport, turbidity, and conductivity	Descriptions of dissolved and suspended solids in water such as turbidity, suspended or dissolved solids, conductance				
	F50	Water temperature	Water temperature				
Geomorphology	F15	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				
	F16	Channel	Channel properties such as bankfull width, wetted width, bankfull discharge, channel slope, braided channel, channelization				
	F17	Floodplain valley	Metrics related to channel confinement, entrenchment, migration, etc.				

 Table 2.1. River functions and their descriptions used as indicators of the effects of hydropower on the river environment. From Pracheil et al. (in review). (continued)

Table 2.1. River functions and their descriptions used as indicators of the effects of hydropower on the river environment. From Pracheil et al. (in review). (continued)

Function Level	Code	River Function Name	River Function Description				
	F18	Sediment and substrate	Sediment and substrate properties such as substrate particle size, bedload, sediment entrainment or deposition, bedrock composition				
Connectivity and	F12	Basin area	Some aspect of area of river basin				
Fragmentation	F13	Dendritic network and riverscape	Fragment length, dendritic connectivity index, barrier index, river distance between dams and projects				
	F14	Fish passage	Mitigated fish passage, including presence of upstream or downstream passage or length of bypass				
Water Quantity	F24	Basin attributes	Attributes related to factors that influence hydrology (or were used in the context of hydrology), such as climate and precipitation				
	F25	Diversion	Quantitative properties of diversions such as volume or discharge of diversion or water for other uses				
	F26- F31	Downstream discharge	Downstream discharge magnitude, duration, rate of change, and timing associated with a specific flow condition (Poff et al. 1997).				
	F32	Groundwater	Groundwater characteristics				
	F33	Reservoir hydrology	Reservoir hydrological characteristics such as residence time, reservoir fluctuation, reservoir surface area, or degree of regulation				
	F34- F39	Upstream inflows	Upstream inflow magnitude, duration, rate of change, and timing associated with a specific flow condition (Poff et al. 1997).				
Landscape	F19	Area impacted, project area	Project boundary area, area impacted by the project as whole, not related to reservoir inundation or land cover				
	F20	Floodplain or riparian vegetation	Properties of floodplain or riparian vegetation such as riparian encroachment or floodplain area				
	F21	Land cover class	Type of land cover, changes in land cover				
	F22	Protected land	Spatial properties of protected lands including losses or increases				
	F23	Reservoir inundation	Reservoir area, upland or floodplain inundation, biomass inundated/lost				

3. INSTRUCTIONS FOR USE

3.1.1 Navigating the Questionnaire

The Questionnaire is a Microsoft Excel file that includes 10 spreadsheets. The spreadsheets include macro-enable features, such as navigation buttons and print commands. Below is a list of each spreadsheet and its function.

- **Instructions** General overview of the questionnaire and a brief version of the details provided in the instructions
- **Questionnaire** List of structured questions organized into major themes and pull-down lists of alternative responses to each answer and whether the question is relevant to specific taxa
- **Summary** Table summarizing the responses to questions associated with each of the river functions. This tabular summary includes the responses according to different spatial scales and taxa.
- **Bar Plots** These three figures summarize the results of the tabular information from the "Summary" Spreadsheet
- **Spider Diagram** this diagram provides a different way to visualize information from the "Summary" spreadsheet. The spider diagram graphically depicts the evidence that a river function is affected by hydropower development or operations. Specifically, the diagram represents the proportion of questions answered "yes" pertaining to each of the river functions.
- **Question_Details**: List of questions and their attributes including references, spatial scale, and other information. These specific attributes include the following:
 - Project type type of hydropower projects of potential relevance (EHA & NPD existing hydropower assets and non-powered dams; All refers to any type of hydropower project)
 - Area Spatial scale of relevance to a given question
 - Biota an indication of whether question is directly related to biota ("Y"= Yes, "N"=No).
 - Taxa an indication of whether answer to the question could be taxa specific
 - KeyQ an indication of whether the question is a "key" structural question or not (where some answers might depend on others) ("Y"= Yes, "N"=No).
 - Reference literature reference used to develop the question
- **Bibliography**: Bibliography of all references used to create questions
- **Q_DB**: Database of unique question-river function combinations used to automatically calculate summary tables based on responses in the questionnaire. [Note: Alteration of the database content or structure will influence the summary output and diagrams. Users should not modify unless they have good reason to do so and are familiar with Microsoft Excel Visual Basic programming].
- List: Used to create standard values for entry in Questionnaire. [Note: Alteration of the list will influence the questionnaire, summary output, and diagrams. Users should not modify unless they have good reason to do so and are familiar with Microsoft Excel Visual Basic programming].

When you open the Excel file, you will be prompted to enable the macro-enabled features. Click "yes" when prompted whether you want to "update" links to external sources. Navigate to the "Instructions" spreadsheet and review the instructions (Figure 2.1). Get familiar with all spreadsheets mentioned above.



Figure 2.1. Instruction spreadsheet providing an overview of background, purpose, and general insructions for use.

3.1.2 Completing the Questionnaire

- Navigate to the Questionnaire spreadsheet (Figure 2.2). Answer questions using drop-down boxes (first response option highlighted in yellow) see Figure 2.3.
- If a question is unclear or confusing, use the navigation buttons beside each question (red circle, Figure 3A) to navigate to the "More Info" Spreadsheet (Figure 2.3B). Additional justification is provided for questions prone to interpretation or needing more information. An example is highlighted in yellow (Figure 3B). Navigation buttons are available to allow you to conveniently return back to the same place on the questionnaire (red circle, Figure 2.3B)
- Where relevant, be sure to select whether a question pertains to a specific taxa by selecting "Yes" for each respective column that applies, or "No" if a question does not apply to a given taxa, or if you're uncertain, then select "uncertain" (Figure 2.4).
- Once you have completed all answers to the Questionnaire, you can click on the "Go to Summary" button to navigate to the "Summary" spreadsheet (red circle, Figure 2.5).

AutoSa	ve 💽 🖫 🖉 🤆 🔹 DST_EHA&NPD_RFLAT - Excel				Mcmanama	, Ryan A.	æ –		/×_
File	Home Insert Developer Page Lavout Formulas Data Review View Add-ins Help XL Toolbox 🖓 Tell me what you want to do						🖻 Share	Comme	ants
Paste CI	(cut Cathering - 11 - A A Spond Painter Format Painter poord c Cathering - 11 - A A A Spond Painter Format Painter Conditional Format as Spond Painter Center - Spond Painter Format Painter Center - Spond Painter	mat ≼] AutoSu] Fill ~ > Clear *	m * A Z Sort Filter Editing	& Find & * Select *	Ideas			^
B117	• I X V Jz Do point and lateral bars show signs of inactive maintenance (i.e., covered in vegetation, little influence of deposition and erosion by flows)?								Â
1 A	8	с	D	E	F	G	н	1	_
2							Taxa	Specific Res	spor
3 Let's	talk about the basin context.	Answer	1 [Fish	Amphibian	Bird	Mammal	Reptile	Cr
106 Q_119	Is the reservoir discharge a hypolimnetic or epilimnetic release?	Uncertain							
107 Q_43	Do noxious, invasive, or hyperabundant algal blooms or matts (e.g., Didymo) occur in the downstream river of the project?	Uncertain							
108 Channe	rl geomorphology								
109 Q_59	Does the dam and reservoir prevent the majority of bedload from upstream sources from reaching reaches below dam?	Uncertain							
110 Q_15	Are sufficial stream bed grain sizes appear very coarse or devoit of sand and gravel substrates compared to neighboring streams of similar geology and gradient?	Uncertain	Q15 Info	60 70					
112 0 89	Is excess segumentation and situation apparent in downstream river compared to neighboring streams or similar geology and gradient?	Uncertain	Q103 Info						
112 0200	Dees ne scream channer appear right y soonizer o'n right channesteu'r	oncertain	Case mijo	·					
113 Q_58	Does the channel appear excessively miniturized?	Uncertain	Q58 info				N	ot Applica	pie
114 Q_112	Is the channel confined by embankments (i.e. roads, levees) or unable to migrate if relevant?	Uncertain							
115 Q_113	Is the channel slope high [>=2%) and have low sinuosity (<1.2) (e.g., high stream power presenting more shear on streambel]?	Uncertain							
117 0 45	Is right an vegetation encroaching the channer Does the channel appear excessively and uncharacteristically praided? Do note that all bares have show since of inactive mystematics. Bits influence of denotition and accience by flows12	Uncertain	dine wo						
118 Eloodo	bor point and areas and a safety and a safety of mactive maintenance (c.e., covered in vegetation, note material or uppartion and eromony nows)	oncertain							
119 0 57	Does signs of scouring during high-flow seasons or high-flow activity appear limited?	Uncertain	OSZ info						
120 Q 98	Have operations reduced floodplain inundation to be infrequent for this system (less than 50% based on expected or target ranges)?	Uncertain	QSE info						
121 0 12	Are noticed of the historically active floodelale surrents in active floodelale surrents in active of the historically active floodelale surrents in active of the historically active floodelale surrents in active of the historically active floodelale surrents in active of the historical surrents in active	Uncertain					N	ot Applica	bla
122 0 07	Ne portonis or the instortionity active indoction and the first matching to a standard and any point during most years; Ne portonis or the instortionity active indoction of the matching to a standard and any point during most years; Many hardwards under the matching of the matching to a standard and any point during most years;	Uncertain						ac replace	
123 0 6	nave backwaters, wetanis, or obows been cut on more expected (i.e., natural or target range) exchange or nows and might now activity? Are Booding used atting in spinish and booding and and and a spinish and	Uncertain	(ga) 1050						
124 Q 5	Are floodplain veetation communities making involve premarily protein species?	Uncertain							
125 126									
127 Critte	rrs - Finned, Fuzzy, and Fabulous								врог
128 Genera	I Biological Conditions Downstream	Answer	1 1	Fish	Amphibian	Bird	Mammal	Reptile	Cr
129 0 145	Do Koala bears ordur near your project 2. Love Koala bears	Uncertain	Q145 info				N	at Applica	56
130 0 52	Deex acute community to heave the second acute a	Uncertain	052 info	Uncertain	Uncertain	Uncertain	Uncertain	Uncertain	extense U
131 Q 3	Are aquatic communities dominated by one or a few species (relative to expected richness)?	Uncertain	Olinfe	Uncertain	Uncertain	Uncertain	Uncertain	Uncertain	t ü
122 0 124		1 Inconstanting	do info				N	at Applica	(SE
122 0 20	is the hist community unnaturally dominated by generalists (e.g., somish, cosmopolian species).	Uncertain		Uncortain	Uncortain	Uscartain	Uncertain	Uncontaio	indahi .
134 0 28	Are a matic indicator revision or yourset removement physical contractions of the second seco	Uncertain	028 info	Uncertain	Uncertain	Uncertain	Uncertain	Uncertain	ti
135 Q 2	Are certain fluvial specialists requiring distinct flow regimes missing from the downstream river community?	Uncertain	0214	Uncertain	Uncertain	Uncertain	Uncertain	Uncertain	tü
136 Q 4	Are aquatic species that require certain turbidity levels missing from the downstream river community or rare?	Uncertain	Oficto	Uncertain	Uncertain	Uncertain	Uncertain	Uncertain	Ū.v
4	Instructions Ouestionnaire Summary Bar Plots Spider Diagram Question Details More info Node temp Edge temp Bibl		1.140)					
					Ħ			+	80%

Figure 2.2. Questionnaire spreadsheet.

	С	D							
					A IN	в	с	D	
					1	Question	More Info		
An	swer		F		Q_138	Under baseflow conditions, do parts of the channel remain dry or uninundated, potentially limiting habitat for some guilds?		Tennant 1976; Orth & Maughn 1981; Travnichek & Maceina 1994; Freeman et al. 2001	
Un	certain				0_91	Has past mitigation or instream flow proved unsuccessful at improving ecological conditions in project waters?		McManamay et al. 2013; Bednarek & Hart 2005	1
Un	certain				103	Does the downstream river (or streams in the region) have "losing" reaches or strong alternating patterns of "losing" and "gaining" systems?	 Losing reaches refer to stream signments where discharge decreases with distance downstream because surface waters re-enter groundwater or subsurface areas. "Gaining! reaches are just the opposite. 	1998; Stromberg et al. 2007; Bond et al. 2010	
Lin	cortain				Q_119	is the reservoir discharge a hypolimnetic or epilimnetic release?		Webb and Walling 1997; Krause et al. 2005; Olden and Naiman 2010; McManamay et al. 2013; Preece &	
UII	certam				104			Jones 2002	
Un	certain	Q15 Info			Q_43	Do noxious, invasive, or hyperabundant algal blooms or matts (e.g., Didymo) occur in the downstream river of the project?		Cooke 1980; Thomson et al. 2005; Flinders & Hart 2009	
Un	certain	Q103 Info		\	105 106 Channel a	eomorphology		1	-
U	certain	Q88 Info			Q_59	Does the dam and reservoir prevent the majority of bedload from upstream sources from reaching reaches below dam?		Kondolf et al. 1997; Graf 2006; Grant 2012; Csiki & Rhoads 2014	
Uh	certain	Q58 Info			Q_15	Are surficial stream bed grain sizes appear very coarse or devoit of sand and gravel substrates compared to neighboring streams of similar geology and gradient?	This might require comparing reaches downstream of the dam to neighboring rivers of similar geologic settings and valley type	Kondolf et al. 1997; Brandt 2000; Graf 2006; McManamy et al. 2010; Grant 2012; Kobayashi et al. 2008	
Uh	certain				Q_103	Is excess sedimentation and siltation apparent in downstream river compared to neighboring streams of similar geology and modest2	see Q15. "Excess" suggests that more sediment and siltation is found in the river compared to what would be expected through comparisons with other streams.	Baker et al. 2010;	
U	certain				103	Branders	1	1	
Un	certain	Q108 Info		/					
Un	certain								

Figure 2.3. (A) Inset displays the response to questions provided by a drop-down list. The response option for the first question is highlighted in yellow. Red circle highlights the navigation buttons to the "More_info" spreadsheet. (B) the "More_info" spreadsheet provides more clarity or explanation behind the questions.

	E	F	G	Н	1	J	К	L	М			
	Taxa-Specific Response											
	Fish	Amphibian	Bird	Mammal	Reptile	Crustacean	Bivalve	Insect	Plant			
nfo												
nto	Not Applicable											
Info												
nfo												
Info				- 54c		ole 👘						
nfo												
Info												
nfo												
nfo												
nfo						0.5						
						•16 .						
	Uncertain	Uncertain	Uncertain	Uncertain	Uncertain	Uncertain	Uncertain	Uncertain	Uncertain			
	Uncertain	Uncertain	Uncertain	Uncertain	Uncertain	Uncertain	Uncertain	Uncertain	Uncertain			
	Uncertain	Uncertain	Uncertain	Uncertain	Uncertain	Uncertain	Uncertain	Uncertain	Uncertain			

Figure 2.4. Section of questionnaire for determining whether specific taxa (columns) apply to each question. The first response is highlighted in yellow.

Q_38	Do any tish have hemorrhaging or bloating of stomach, odd swimming behavior, presence of bubbles under thin dermal layers?									
Q_37	Do any fish have external lesions, curved spines, malformations?									
Biologica	al Sampling Considerations									
Q_125	Is there a need to conduct routine community surveys or monitoring of populations or communities?									
Q_99	Have past biological sampling methodologies within the project area been heterogenous (conducted under a variety of methods)?									
Q_34	Could abundance or density values of focal species provide insights into habitat needs, suitability, or limited habitats?									
Q_11	Are particular methods well suited for collecting a given focal species while other methods are maladapted for species detection?									
Q_13	Are sensitive species or focal species life histories, reproductive behaviors, and habitat requirements poorly known?									
Q_14	Are sensitive species or species expected to be common rare in surveys?									
Q_139	Will habitat-based instream flow criteria (IFIM, PHABSM) likely be used for evaluating alternative flow regimes?									
Q_48	Do surveys suggest that specific age cohorts, size groups, or life stages are missing from occurrences of rare or of-concern species?									
Q_96	Have any habitat classification measures been conducted or proposed for the downstream river or project lands (e.g., mesohabitat classification for PHABSIM) 1									
Done	with Questions?									
	Go to Summary Go to Bar Plot Figures Go to Spider Diagrams									

Figure 2.5. At the bottom of the questionnaire, there is a navigation button (red circle) that takes user to the tabular summary.

3.1.3 Interpreting the Questionnaire Output

- The Summary spreadsheet provides a tabular summary of the number of questions answered "yes", "no", or "uncertain" (blue circle) related to a given river function (highlighted in yellow, Figure 2.6). Recall that a given question can pertain to more than one river function.
- The number of questions answered "yes" and relevant to specific taxa (black circle) or particular spatial scales (green circle) are also summarized (Figure 2.6).
- Click on the "Go to Bar Plot Figures" (red circle, Figure 2.6) to navigate to that page.

Go to Bar	Plot Figures	Go to Spider Diagram				
				-	-	
	1			An	swers	
action Level	Cose	River Function Name	Yes	No	Uncertain	Total
ta and Biodiversity	F1	Abundance, density	0	0	5	5
	F51	Algae/ primary productivity (88)	0	0		6
	F5	Behavior, movement, colonization, extinction	0	0	5	5
	F6	Demographics, age, sex, size	0	0	5	5
	F7	Fitness, survival, growth, condition, reproduction, mortality	0	0	5	5
	F8	Functional group, or species or trait composition	0	0	6	6
	F9	Genetics, mixing, metapopulation	0	0	5	5
	F10	Habitat, critical habitat, or surrogates of such	0	0	6	6
	F11	Internal composition nutrient abnormalities	0	0	5	5
	F2	Life history trait characteristics	0	0	6	6
	F3	Presence, absence, occupancy, or detection	0	0	6	6
	F4	Species diversity	0	0	6	6
ter Quality	F40	Algae/ primary productivity (WQ)	0	0	6	6
	F41	Buffering capacity	0	0	5	5
	F42	Dissolved gasses	0	0	4	4
	F43	Dissolved oxygen	0	0	7	7
	F44	Ecosystem function	0	0	5	5
	F45	Gas emissions	0	0	5	5
	F46	Key elements	0	0	6	6
	F47	Macromolecular pollutants	0	0	5	5
	F48	Nutrients and organic material (C, N, P)	0	0	6	6
	F49	Solid transport, turbidity, and conductivity	0	0	8	8
	F50	Water temperature	0	0	5	5
omorphology	612	Catchment and basin attributes	0	0	4	4
	F10	Channel	0	0	6	6
	F17	Hoodplain valley	0	0	7	7
	F18	Sediment and substrate	0	0	7	7
opertivity and Fragmentation	£12	Basin area	0	0	6	6
,,	F13	Dendritic network and riverscape	0	0	5	5
	F14	Fish passage	0	0	7	7
	F52	Turbine/Spill & Downstream passage	0	0	6	6
		and the second sec				
ter Quantity	F24	Basin attributes	0	0	6	6
	estionnaire	ummany Bar Plots Spider Diagram (Juestion	Dotaile	More info	Nod

Figure 2.6. Summary spreasheet. River functions are listed in rows (up to down), whereas counts of responses are in columns. Total enumeration of "yes", "no", and "uncertaint" answers relevant to each river function are provided in the answers section (Blue circle). The total number of questions answered "yes" and applicable to each taxa-type are provided in the middle section (black circle), whereas the number of questions answered "yes" and applicable to specific spatial scales are provided in the far right section (green circle). Navigation buttons to the bar plot figures (red circle) and spider diagram is provided.

• Once on the Bar_Plot spreadsheet (Figure 2.7), you will see three bar plots, two of which have summary pie charts underneath. You will notice that there are navigation buttons provided but also an ability to print the bar charts to .pdf files to save the output.

Go to Summary	Go to Spider Diagram	Print Bar Charts	Explanation: The plots represent the evidence that studies or assessmer ligher percentages of questions answered "yes" for any riv "yes" for any river function can be related to specific spatia
River Functions	Percentage of questions answered "Yes", "No", or "Uncertain"	River Functions	Percentage of questions relevant to spatial scales
Biota and Biodiversity Algue/ primary productivity (B Behavior, movement, colonization, ediricoli Demographica, age, tes, siz Fitness, survival, growth, condition, reproduction, mortal Functional group, or pecied or trait compositio Genetics, mixing, metapopulatio Habitar, critical habitar, or surrageses of suc	OK 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%	5% Biota and Biodiversity Algase/primary productivity (b) Behavior, movement, colonization, estinction Demographics, age, set, size Fitnes, sunvival, growth, condition, reproduction, mortality Fitnetional group, or species or trais composition Genetics, mixing, metapopulation Habitat, critical habitat, oristange of such	10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

Figure 2.7. Top of Bar_plot spreadsheet with navigation buttons and first two bar plots.

• The bar plot on the far left represents the percentage of "yes", "no", and "uncertain" questions for a given river function (Figures 2.7-8). In short, they summarize the evidence that studies or assessments of specific environmental issues (i.e. river functions) may be warranted based on percentage of "yes"

responses and issues that may be uncertain. River functions are listed vertically and represent different facets of the environment (Figure 2.8).

- Higher percentages of questions answered "yes" for any river function indicates more evidence that a river function is affected by development or operations at the facility. This may suggest that studies or assessments for that river function may be needed.
- Additionally, the percentage of questions answered "yes" for any river function can be related to specific spatial scales (Figure 2.9) or specific taxa that are most relevant in order to study or assess that function (Figure 2.10). This provides users with an indication of what spatial scales are most applicable to studies and the taxonomic groups that may require the most attention.
- Find the navigation buttons at the top of the bar_plot spreadsheet and click on "Go to Spider Diagram" (Figure 2.7)
- The Spider diagram (Figure 2.11) relies on the same information presented in Figure 2.8 but displays it differently. The spider diagram represents evidence of which river functions may be affected by development or operations at the facility (Figure 2.11). Specifically, the proportion of questions answered "yes" for each river function provide an indication that the project has or will effect specific environmental factors. For instance, if River Function F1 Abundance/density has a value of 0.75, then this indicates that 75% of questions related to abundance and density were answered "yes". This suggests that studies monitoring abundance may be needed. Refer to the "relevant taxa" in the "Bar Plot Figures" to determine which taxa may need to be monitored.
- The Spider_Diagram spreadsheet provides navigational buttons and print commands (Figure 2.12). Users can print either the spider diagram or the river function summary table.



Percentage of questions answered "Yes", "No", or "Uncertain"

Figure 2.8. Bar plot depicting the percentage of "yes", "no", and "uncertain" responses relevant to each of the river functions. The example provided represents responses to the questionnaire with respect to Smoky Mountain Hydropower Project in North Carolina and Tennesee.





Figure 2.9. Bar plot depicting the percentage of "yes" responses that were relevant to specific spatial scales and a given river function. The pie chart provides a summary of all questions answered "yes" and relevant to a given spatial scales. The example provided represents responses to the questionnaire with respect to Smoky Mountain Hydropower Project in North Carolina and Tennesee. In this case, most "yes" responses were relevant to the entire project or basin or environments downstream. Fewer responses were relevant to the reservoirs associated with the project.



Figure 2.10. Bar plot depicting the percentage of "yes" responses that were relevant to specific taxa and a given river function. The pie chart provides a summary of all questions answered "yes" and relevant to a given taxonomic group. The example provided represents responses to the questionnaire with respect to Smoky Mountain Hydropower Project in North Carolina and Tennesee. In this case, most "yes" responses were relevant to fish and mussels; however, many taxa were relevant to the Smoky Mountain project as there are multiple developments and significant land assets.



Proportion of Questions Answered "Yes" for each River Function

Figure 2.11. Spider diagram depicting the proportion of questions answered "Yes" for each river function. The diagram provides the same information captured in Figure 2.8. These proportions represent the likelihood that a river function is affected by the hydropower facility and ranges from 0 to 1. This example is provided for Smoky Mountain Hydropower Project in North Carolina and Tennessee. The diagram suggests that certain river functions in all six categories are affected by operations, with many of the biota and biodiversity functions having a high likelihood of being affected.

Proportion of Questions Answered "Yes" for e	ach River Function	Function L Code	River Function Name	Yes	No	Uncertain	Total	Proportion Yes
		Biota and F1	Abundance, density	0	0	5	5	0
		Biodivers F51	Algae/ primary productivity (BB)	0	0	6	6	0
F1		F5	Behavior, movement, colonization, extinct	0	0	5	5	0
Landcover F21F22F231 F51F5 F6 F7 F8	Biota & Biodiversity	F6	Demographics, age, sex, size	0	0	5	5	0
	7	F7	Fitness, survival, growth, condition, reproc	0	0	5	5	0
	F8	F8	Functional group, or species or trait comp	0	0	6	6	0
F9		F9	Genetics, mixing, metapopulation	0	0	5	5	0
F34-F39	F10	F10	Habitat, critical habitat, or surrogates of s	0	0	6	6	0
F32 0.5	↓ F11	F11	Internal composition nutrient abnormalit	0	0	5	5	0
Water F26-F31	F2	F2	Life history trait characteristics	0	0	6	6	0
Quantity 525 0.25	1 52	F3	Presence, absence, occupancy, or detectio	0	0	6	6	0
	113	F4	Species diversity	0	0	6	6	0
F24 0	F4				0	6	-	-
		Water F40	Algae/ primary productivity (wq)	0	0	0		0
F52	F40	Quality r41	Directing capacity	0	0	2	2	U
F14	F41	F42	Dissolved gasses	0	0	4	4	0
E12	EAD	F43	Econstan function	0	0			0
Connectivity &	F42	F44	Ecosystem function	0	0	5	2	0
Fragmentation F12	F43	F40	Gas emissions	0	0	6	-	0
F10	F44	F40	Massemologular pollutants	0	0	6	6	0
F 10 F17	46	E49	Nutrients and erappic material (C. N. D)	0	0	5		0
F16F15 F40F48F47	Weter	F40	Solid transport turbidity and conductivity	0	0	0	0	0
F50 F50	Quality	F50	Water temperature	0	0	6	6	0
Geomorphology	Quancy	150	water temperature					0
		Geomorp F15	Catchment and basin attributes	0	0	4	4	0
		F16	Channel	0	0	6	6	0
diagram represents evidence that studies or assessments of potential environmental issue may		F17	Floodplain valley	0	0	7	7	0
warranted. The proportion of questions answered "yes" for each river function provide an indication		F18	Sediment and substrate	0	0	7	7	0
he project has or will effect specific environmental factors. For inst	ance, if River Function							
oundance/density has a value of 0.75, then this indicates that 75%	of questions related to abundance	Connectiv F12	Basin area	0	0	6	6	0
d density were answered "yes". This suggests that studies monitoring abundance may be needed.		and F13	Dendritic network and riverscape	0	0	5	5	0
to the "relevant taxa" in the "Bar Plot Figures" to determine which	axa may need to be monitored.	Fragment F14	Fish passage	0	0	7	7	0
		F52	Turbine/Spill & Downstream passage	0	0	6	6	0
		Water F24	Basin attributes	0	0	6	6	0
Go to Summary Go to Bar Plot Figures	Print Spider Diagram	Quantity F25	Diversion	0	0	9	9	0
		F26-F31	Downstream discharge	0	0	7	7	0
		F32	Groundwater	0	0	5	5	0
		F34-F39	Reservoir hydrology	0	0	7	7	0
		Landscap F19	Area impacted, project area	0	0	4	4	0
	Drint River Eurotion Table	F20	Floodplain or riparian vegetation	0	0	6	6	Ō
	Print River Function Table	F21	Land cover class	0	0	5	5	0
		F22	Protected land	0	0	5	5	0
		F23	Reservoir inundation	0	0	6	6	0

Figure 2.12. Spider diagram spreadsheet provides navigational buttons (to navigate to other sheets) and provides convenient print buttons to print the diagram or the river function summary table to .pdf.

4. QUESTIONNAIRE CROSS-CUT WITH REGULATORY CRITERIA

4.1 BACKGROUND

The Questionnaire is a scientific tool based on scientific principles. It is flexible in that it can easily be applied to many different regulatory procedures, including FERC licensing. The Code of Federal Regulations (CFR) Title 18-Conservation of Power and Water Resources Chapter 1 outlines the role and conduct of FERC and the standards and procedures of the federal hydropower licensing process. Subchapter 5 (CFR 18, § 5) outlines the Integrated Licensing Process, which includes criteria for stakeholders making study requests (CFR 18, § 5.9) and criteria for the applicant in developing a study plan (CFR 18, § 5.11) (see FERC 2005). Appropriate use of the Questionnaire, and the results obtained from its use, can generally be helpful in addressing the following sections of § 5.9 (b) for study request criteria, which are equally analogous to sections of § 5.11 (d):

- § 5.9 (b.1). Describe the goals and objectives of each study proposal and the information to be obtained
- § 5.9 (b.4). Describe the existing information concerning the subject of the study proposal, and the need for additional information
- § 5.9 (b.5). Explain any nexus between project operations and effects (direct, indirect, and/or cumulative) on the resource to be studied, and how they study results would inform the development of license requirements.

4.1.1 § 5.9 (b.1) and § 5.11 (d.1)

In making a study request or in developing a study plan, stakeholders and applicants, must establish the goals and objectives of a given study and what information is required to meet those objectives. The Questionnaire assists all parties in establishing and understanding the rationale and justification behind why some aspects of the river environment (i.e., functions) are likely to have been affected by operations, and why others have not been. It also requires all parties to critically assess environmental conditions, compile and analyze existing information on environmental conditions and effects, and gain consensus over facts and data, in hopes of identifying natural resource issues that are well-justified by scientific information. Alternatively, the Questionnaire also highlights areas that are highly uncertain and may require additional information to fully understand. Finally, the nature of questions in the Questionnaire helps develop the scope and understand the role of specific studies in identifying causal relationships between operations and environmental conditions. In this way, the Questionnaire identifies the most relevant spatial scales and taxa for study or mitigation design.

The Questionnaire is a tool that supports, but does not replace, complex negotiation dialogue and procedures. In most relicensings, there is a multitude of study requests that could be used to address the natural resource issues identified. The Questionnaire provides all parties with a transparent evaluation of the environmental conditions present at the facility that have the highest likelihood of being impacted by construction or operation activities at a variety of temporal and spatial scales based on existing information. While the Questionnaire tallies the types of responses for questions about each function, it does not set thresholds for the number of "yes" responses indicate a river function should or should not be studied. Similarly, the questionnaire does not how or whether impacts to a river function could be mitigated.

4.1.2 § 5.9 (b.4) and § 5.11 (d.3)

Studies are typically used to fill information gaps, i.e. gaps in knowledge about project operation effects on environmental resources and potential outcomes of alternative mitigation strategies. Obviously, justifying any study or planning for a study requires parties to be cognizant of existing information, from the Pre-Application Document (PAD) or other sources. This prevents studies from being redundant with past efforts (e.g. previous relicensing) or, in the least, helps ensure studies are appropriately focused on filling information gaps. The use of the Questionnaire facilitates the process of identifying existing information. The instructions of the Questionnaire explicitly stipulate that to answer any question "yes" or "no" requires that a user must provide some existing information (e.g., past study, data, picture, stream gage reading, etc.) to qualify the response. The Questionnaire indirectly benefits the study request and study plan process through assisting in the development of the PAD. If an applicant uses the Questionnaire to develop the PAD, the early process of gathering and documenting sources of information could provide more efficient communication among parties and result in time savings in sequent licensing steps.

The negotiation process must determine whether the existing information is sufficient to understand project effects on the environment or whether more information is needed. The Questionnaire helps to identify environmental resources whose condition is highly uncertain and requires gathering of more information or the justification for a study request. The Questionnaire also helps identify the type and spatiotemporal scales of data required to understand environmental conditions.

4.1.3 § 5.9 (b.5) and § 5.11 (d.4)

The Questionnaire can assist parties determine what effected resources can be mitigated through understanding causal linkages between the project and resources, including the role of diffuse stressors at larger spatial- and temporal-scales. Clear connections between the project operations and the effects on environmental resources must be established. The Questionnaire helps all parties draw lines of inference between project operations and direct or indirect effects on river functions. Questions were developed from a review of scientific literature and focus on well-established and common relationships between hydropower and river environmental conditions are related to project operations or an artifact of human activities upstream or in adjacent basins outside the applicant's control or outside the purview of the project. For instance, several questions ask whether hydrology or water quality conditions at the project are influenced from upstream sources. In these cases, the role of project operations on the current environmental conditions and causal factors, some of which cannot be mitigated with a cost-effective solution.

The Questionnaire provides an objective basis from which study request and plans can be made. A highly controversial aspect of understanding project nexus with environmental resources is that of delineating the baseline condition – i.e. the reference or standard from which one measures the current state of resources. The identification of the quantity and identity of resources are affected by project operations is contingent on baseline delineation. FERC's policy defines baseline conditions as the environmental condition at the time of licensing, specifically stipulating that applicants are generally not required to recreate pre-project conditions (i.e., historical conditions) (FERC 2012). However, in order to evaluate the effects of project operations and alternatives, FERC requires that continuing effects on resources be assessed (presumably including those established since the time of development), as long as the purpose of the information is to evaluate appropriate mitigation under continued project operation (FERC 2012). The Questionnaire provides a transparent evaluation of environmental conditions and a tally of which aspects of the river environment have been affected by project operations. Some of the questions do

require users to identify a baseline to make comparisons and understand environmental effects appropriately. These comparisons may include evaluating conditions at neighboring regulated or non-regulated river systems to objectively establish causal relationships between project operations and resources, but also understand what factors can be reasonably mitigated. The Questionnaire is flexible in that questions can be answered differently depending on how the baseline condition is defined. Given that the questionnaire is grounded in scientific literature that predominately measures resource effects through comparisons of pre- and post- development and regulated and non-regulated systems, one suggestion is that the Questionnaire be used to develop a holistic understanding of the current state of the river ecosystem (and associated terrestrial ecosystems) relative to stated resource goals using river functions as indicators. Establishing this understanding does not suggest that mitigation is warranted or even achievable under continued project operations. However, a comprehensive understanding of the ecosystem characteristics inclusive of present and historical stressors can be useful in isolating the most meaningful causal factors between project operations and environmental conditions including which factors can be mitigated to improve conditions.

5. ACKNOWLEDGEMENTS

This research was sponsored by the U.S. Department of Energy, Water Power Technologies Office within the Office of Energy Efficiency and Renewable Energy under contract DEAC05-00OR22725. We wish to thank the Mission and Science Advisory Boards for their roles in evaluating the questionnaire and providing valuable feedback. We thank Tim Welch, Dana McCoskey, and Corey Vezina for their guidance on the project.

6. **REFERENCES**

- FERC (Federal Energy Regulatory Commission). 2005. Understanding the Study Criteria. Integrated Licensing Process. Office of Energy Projects. April 6, 2005. Available at: https://www.ferc.gov/industries/hydropower/gen-info/licensing/ilp/eff-eva/study-criteria.pdf
- FERC (Federal Energy Regulatory Commission). 2012. A guide to understanding and applying the Integrated Licensing Process Study Criteria. Office of Energy Projects. March 2012. Available at: <u>https://www.ferc.gov/industries/hydropower/gen-info/guidelines/guide-study-criteria.pdf</u>
- McManamay, R.A., S.K. Brewer, H. Jager, M. Troia. 2016a. Organizing environmental flow frameworks to meet US Hydropower mitigation needs. Environmental Management 58: 365-385
- McManamay, R.A., C. Oigbokie, S-C. Kao, M.S. Bevelhimer. 2016b. A classification of US hydropower dams by their modes of operation. River Research and Applications DOI: 10.1002/rra.3004
- McManamay, R.A., B.K. Peoples, D.J. Orth, C.A. Dolloff, and D.C. Matthews. 2015a. Isolating causal pathways between flow and fish in the regulated river hierarchy. Canadian Journal of Fisheries and Aquatic Sciences 72: 1731-1748.
- McManamay, R.A., N. Samu, S-C. Kao, M.S. Bevelhimer, and S.C. Hetrick. 2015b. A multi-scale spatial approach to address environmental effects of small hydropower development. Environmental Management 55: 217-243.
- McManamay, R.A. 2014. Quantifying and Generalizing Hydrologic Responses to Dam Regulation using a Statistical Modeling Approach. Journal of Hydrology 519: 1278-1296.

- McManamay, R.A., D.J. Orth, C.A. Dolloff, D.M. Mathews. 2013b. Application of the ELOHA framework to regulated rivers in the Upper Tennessee River basin. Environmental Management 51:1210–1235.
- McManamay, R.A., D.J. Orth, J. Kauffman, M.D. Davis. 2013c. A database and meta-analysis of ecological responses to flow in the South Atlantic Region. Southeastern Naturalist 12 (Monograph 5): 1-36.
- McManamay, R.A., D.J. Orth, C.A. Dolloff. 2012. Revisiting the homogenization of dammed rivers in the Southeastern US. Journal of Hydrology 424-425: 217-237.
- McManamay, R. A., D. J. Orth, C. A. Dolloff, and M. A. Cantrell. 2010. Gravel addition as a habitat restoration technique for tailwaters. North American Journal of Fisheries Management 30:1238-1257.
- Norris, R.H., J.A. Webb, S.J. Nichols, M.J. Stewardson, and E.T. Harrison. 2012. Analyzing cause and effect in environmental assessments: Using weighted evidence from the literature. Freshwater Science 31:5–21.
- Olden, J.D., and Naiman, R.J. 2010. Incorporating thermal regimes into environmental flows assessments: modifying dam operations to restore freshwater ecosystem integrity. Freshw. Biol. 55: 86–107. doi:10.1111/j.1365-2427.2009.02179.x.
- Parish, E., B.M. Pracheil, R.A. McManamay, S.L. Curd, C.R. DeRolph, B.T. Smith. 2019. Review of environmental metrics used across multiple sectors and geographies to evaluate the effects of hydropower development. Applied Energy 238:101-118 https://doi.org/10.1016/j.apenergy.2019.01.038
- Petts G. 1984. Impounded Rivers: Perspective for Ecological Management. John Wiley & Sons: Chichester.
- Poff NL, Hart DD. 2002. How dams vary and why it matters for the emerging science of dam removal. BioScience 52: 659–738.
- Poff, N.L., and J.K.H. Zimmerman. 2010. Ecological responses to altered flow regimes: A literature review to inform the science and management of environmental flows. Freshwater Biology 55:194–205.
- Pracheil, B.M., R.A. McManamay, E.S. Parish, S.L. Curd, B.T. Smith, C.R. DeRolph, A.M. Witt, S. Ames, M.B. Day, W. Graf, D. Infante, D.L. McCoskey, K. Rugani, C. Vezina, T. Welch, A. West. (in review). A checklist of river function indicators for hydropower ecological assessment. Science of the Total Environment.