Title: A Synthesis of Environmental and Recreational Mitigation Requirements at Hydropower
Projects in the United States

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1 ABSTRACT

2 Environmental mitigation plays an important role in the environmentally sustainable development of
3 hydropower resources. However, comprehensive data on mitigation required by the Federal Energy
4 Regulatory Commission (FERC) at United States (US) hydropower projects is lacking. Therefore, our
5 objective was to create a comprehensive database of mitigation required at non-federal hydropower
6 projects and provide a synthesis of available mitigation data. Mitigation data was collated for over 300
7 plants licensed or relicensed from 1998 through 2013. We observed that the majority of FERC mitigation
8 requirements deal with either hydrologic flows or recreation and that hydropower plants in the Pacific
9 Northwest had the highest number of requirements. Our data indicate opportunities exist to further
10 explore hydropower mitigation in the areas of environmental flows, fish passage, and water quality.
11 Connecting these data with ecological outcomes, actual flow data, and larger landscape level information
12 will be necessary to evaluate the effectiveness of mitigation and ultimately inform regulators, managers,
13 and planners.

14 Keywords: environmental mitigation; FERC; hydropower; hydropower policy; environmental flows

15 1. INTRODUCTION

17 The environmental impacts of hydropower, including alteration of flow and sediment regimes,
18 riparian habitat, biodiversity, and water quality (Poff et al., 2007, 1997), disruption of fish migration
19 (Liermann et al., 2012), and fragmentation of habitat (Nilsson et al., 2005), are well established. In the
20 United States (US), the federal regulation of these environmental impacts is a relatively recent
21 development, despite the establishment of federal licensing and oversight of hydropower facilities
22 occurring in 1920 (Richardson, 2000). The authority to determine and issue 30 to 50 year licences for the
23 operation of non-federal hydropower facilities currently falls under the US Federal Energy Regulatory
24 Commission (FERC). Not until the passage of environmental legislation, such as the National
25 Environmental Policy Act in 1970 (NEPA), the Clean Water Act in 1972 (CWA), and the Endangered

Species Act in 1973 (ESA), was FERC required to incorporate environmental protections into project licensing decisions (Kosnik, 2010).

In particular, the passage of the Electric Consumers Protection Act of 1986 (ECPA) substantially changed FERC's consideration of environmental impacts with the requirement that FERC give equal consideration to the protection and enhancement of, and mitigation of damage to, wildlife, environmental quality, and recreational opportunity. Furthermore, a string of court rulings eroded FERC's singular authority to determine environmental mitigation by requiring FERC to include fishway prescriptions from the National Marine Fisheries Service or US Fish and Wildlife Service, as well as minimum streamflow requirements included as part of state water quality certificates (Blumm and Nadol, 2001; Tarlock, 2012). The result was a significant increase in the number of mitigation requirements included in FERC licenses (DeShazo and Freeman, 2005; Kosnik, 2010) and a growing role of other federal and state agencies in the licensing process (Blumm and Nadol, 2001; DeShazo and Freeman, 2005). The FERC and hydropower industry have suggested that this evolving policy context and increased regulatory plurality resulted in increased licensing time and increased uncertainty in mitigation requirements (FERC, 2001; U.S. House Committee on Natural Resources, 2012).

Despite the importance that environmental mitigation requirements play in the licensing process, no comprehensive, centralized mitigation datasets exist for FERC-licensed projects. With this in mind we set out to create a national scale database of mitigation required at FERC-licensed hydropower projects with two intentions. First, relicenses provide a once in every 30- to 50-year opportunity to address environmental concerns at hydropower projects. With over 300 relicence applications anticipated between 2016 and 2026 (FERC, 2015, Appendix A Figure A4), there is new urgency to evaluate and balance the environmental costs of hydropower projects with the associated ancillary benefits. Moreover, environmentally sustainable development of hydropower resources requires addressing socioeconomic and environmental costs and benefits at multiple scales and will require scale appropriate data (Brown et al., 2009; McManamay et al., 2015). Underlying completion of these broad objectives, however, is the

1 need for collated spatial data of FERC-ordered mitigation that can be combined with existing data of past
2 and current ecological conditions to evaluate mitigation effectiveness and feed into decision making
3 frameworks. Second, both developers and regulators face some level of uncertainty in mitigation included
4 by FERC in hydropower licenses due to changes in policy over time (FERC, 2001; U.S. House Committee
5 on Natural Resources, 2012). A comprehensive and up-to-date database provides a resource to evaluate
6 and better anticipate the range and types of mitigation that a project may face prior to licensing
7 proceedings. Here we (1) report the development of a national scale database of mitigation required at
8 non-federal hydropower projects and (2) provide a synthesis of mitigation information and hydropower
9 projects included in the database.

2. METHODS

2.1 DATA SOURCES

We conducted a manual review of FERC hydropower licenses followed by keyword searches to
identify mitigation requirements at licensed hydropower projects and to ensure completeness of
mitigation identification. FERC licenses were obtained from the FERC e-Library
(<http://www.ferc.gov/docs-filing/elibrary.asp>). Because we did not have the resources to review all 2044
FERC licenses (as of March 2016), we limited the manual review to licenses issued from 1998 through
2013 with an assumption that more recently issued licenses would better reflect mitigation requirements
for upcoming relicenses. Hydropower plant attributes were obtained from the National Hydropower Asset
Assessment Program (NHAAP) database (<http://nhaap.ornl.gov>).

2.2 DATABASE DESIGN

Prior to database design, a random sample of twenty licenses was reviewed to identify the types of
data that could be retrieved from the documents and possible mitigation scenarios. We then identified six
broad categories of mitigation and 20 subcategories used to classify specific mitigation types in the
database (Table 1). The tier one and two classifications were derived from major hydropower
environmental impacts and associated mitigation measures outlined in Trussart et al. (2002) and Kumar et

1 al. (2011), which can be summarized as: (1) impacts on biodiversity, (2) barriers to fish migration, (3)
2 changes in aquatic and terrestrial habitat, (4) changes to hydrological regimes, and (5) alteration of water
3 quality. Classifications were exclusive; no mitigation type could be placed in more than one classification
4 and were based on hydropower mitigation literature reviews and expert opinion.

5 We recognize that the classifications are quite broad and many mitigation measures can address
6 multiple objectives. For example, a habitat restoration measure such as downstream gravel restoration
7 might be required as a means to restore aquatic habitat for salmonids or benthic macroinvertebrates, a
8 clear biodiversity implication. However, we made an effort not to infer intent of any mitigation measures
9 due to the limited technical information included within individual licenses and to reduce subjectivity.
10 Therefore, biodiversity mitigation requirements required clearly articulated species-specific protection,
11 restoration efforts, monitoring, or studies. Another example is trash or bar racks, which generally serve to
12 exclude large debris from turbine intakes. However, if a FERC license required the installation of a trash
13 rack for a stated purpose of preventing fish entrainment, it was recorded as fish passage mitigation.
14 Finally, although the recreational requirements imposed within hydropower licenses were not considered
15 as environmental mitigation, we decided to record and include recreation requirements as a sixth
16 classification due to FERC's legislative mandate to consider the protection and mitigation of recreational
17 opportunity.

18 The database was created and populated in Microsoft Access (Microsoft Corporation, Redmond,
19 Washington) with unique hydropower plant identifiers related to hydropower plant attributes in the
20 NHAAP database. Each record in the database includes the identified mitigation, the unique plant
21 identifier, and the category classification of the mitigation. A complete description of the database
22 schema, tables, mitigation, and classifications is included in Appendix A.

Table 1: Mitigation classification used in the database and examples of mitigation included in FERC licenses.

Tier one classification	Tier two classification	Examples of mitigation
Biodiversity	Terrestrial Aquatic	Critical habitat conservation Stocking fish species of concern
Fish passage	Upstream fish passage Downstream fish passage Entrainment Passage planning	Fish ladder Surface collector Guidance net Passage feasibility assessment
Habitat	Fisheries Reservoir Riparian Wetlands	Downstream gravel restoration Noxious plant control Establish riparian buffer zones Wetland protection
Hydrology	Flow mitigation Tailrace minimum flow Bypass minimum flow Sediment Operations	Ramping rates Run-of-river Year-round Sediment/erosion plan Compliance monitoring plan
Recreation	Recreation flow Resources and mitigation Planning	Recreational flow releases Shoreline access Recreational plans or studies
Water quality	Downstream water quality Upstream water quality	Forebay aeration Water quality monitoring

2.3 DATA ANALYSIS

River basins are considered an appropriate framework for aggregation when considering the cumulative environmental effects of hydropower projects (McManamay et al., 2015); therefore, 2-digit Hydrologic Unit Code (HUC2) regions that represent drainages of major river systems were chosen as a unit to aggregate data. We recognize that finer resolution (e.g. HUC6 or HUC8 units) might be more appropriate for linking local ecological condition with hydropower mitigation; however, with the limited sample size we decided that HUC2 regions and states were appropriate units for summarizing broad scale trends. To determine if the spatial distribution of the subset of plants included in the database was representative of all FERC-licensed plants, chi-square goodness of fit tests were conducted to evaluate differences in the distributions of plants per HUC2 and per state in the database to the distributions of all FERC-licensed plants. Summary statistics were aggregated and reported at the HUC2 and state levels with SQL queries to concisely summarize mitigation trends. We anticipated that some trends may occur at these geographic and political units due to trends in state and federal agency behavior and licensing

1 experience within states and regions. These jurisdictional boundaries are not proxies for hydropower plant
2 characteristics, and the variance in plant characteristics that might influence mitigation requirements is
3 quite high (Table 2). Kosnick (2010) found that the numbers of mitigation requirements at hydropower
4 plants are explained not only by different plant characteristics, but most importantly by legislative and
5 institutional influences. The natural extension to the explanatory models developed by Kosnick (2010)
6 includes developing models that predict not only the numbers of mitigation requirements but the types of
7 mitigation requirements. It was beyond the scope of this paper to develop explanatory models between
8 environmental and socio-political predictor variables and mitigation requirements, but the data presented
9 will serve as an initial step for follow-up projects linking mitigation with plant and environmental
10 characteristics with predictive models.

11 **3. RESULTS AND DISCUSSION**

12 The database includes mitigation data from 447 hydropower plants and 309 FERC licenses out of
13 2044 total FERC licensed projects. The discrepancy between the number of licenses and plants occurs
14 because a single FERC license might cover multiple plants and dams. Database summary statistics
15 including number of mitigation requirements, nameplate capacity (nameplate capacity is the registered
16 full load output of a plant), dam height, dam length, number of intervenors, and number of threatened and
17 endangered species mentioned in a license, are reported in Table 2.

Table 2: Summary statistics of 447 hydropower plants in the database.

Variable	Median	Std. Dev.	Min	Max
Mitigation requirements/plant (n)	11	6.0	0	36
-Biodiversity requirements/plant (n)	2.0	1.7	0	9
-Fish passage requirements/plant (n)	0.0	2.2	0	11
-Habitat requirements/plant (n)	1.0	1.3	0	6
-Hydrology requirements/plant (n)	3.0	2.0	0	14
-Recreation requirements/plant (n)	2.6	2.0	0	8
-Water quality requirements/plant (n)	1.0	1.4	0	6
Capacity (MW)	6	173	0.01	2429
Height (ft)	40	81	3	606
Length (ft)	742	3389	20	41900
Intervenors (n)	4.0	7.3	0	39
Threatened/endangered species (n)	1.0	3.0	0	16

The percentage of plants included in the database per HUC2 region ranged from 0 (Rio Grande) to 70% (Tennessee, Figure 1). The chi-square goodness of fit tests indicated that the database plant distributions differed significantly from total plant distributions when compared by HUC2 ($\chi^2 = 82.2$, $DF=18$, $P < 0.01$) and state ($\chi^2 = 125.7$, $DF=45$, $P < 0.01$). Post hoc chi-square goodness of fit tests with Bonferroni corrected α indicated that the California HUC2 region ($\chi^2 = 16.2$, $DF=1$, $P < 0.01$) and the state of California ($\chi^2 = 24.0$, $DF=1$, $P < 0.01$, Appendix A, Figure A5) were the only areas underrepresented in the database. A visual inspection of the percentages of total plants per region shows the California region accounts for 18% of FERC-licensed hydropower plants but only 9% of the plants included in the database (Appendix A, Figure A6). The relatively low proportion of plants included in the database from California should be considered when drawing conclusions about mitigation trends in the region and state.

Figure 1: The percentage of FERC-licensed plants included in the database in each HUC2 region (plants licensed from 1998 through 2013).

3.1 MITIGATION SUMMARY

We identified 132 different types of mitigation and a total of 5,130 mitigation records in 309 FERC licenses. Out of the 5,130 mitigation records, 18% were classified biodiversity, 11% fish passage, 10% habitat, 29% hydrology, 23% recreation, and 10% water quality. Out of the 447 plants in the database, biodiversity mitigation was required at 71%, fish passage at 48%, habitat at 57%, hydrology at 95%, recreation at 82%, and water quality at 53% of plants. The percentage of plants with mitigation summarized by Tier 2 classification and HUC2 region is included in Appendix A, Figure A7.

1 Nationally, there was a mean of 11.5 mitigation requirements per hydropower plant (n=447, SE= 0.3,
2 Figure 2). Regional means ranged from 6.7 (SE=2.1) in the Great Basin to 15.7 (SE=0.9) in the Pacific
3 Northwest. In general, many of the most frequently observed mitigation requirements were types of
4 environmental management plans, monitoring, or studies. Specific mitigation requirements such as fish
5 ladders, temperature control devices, or minimum flow release structures were observed infrequently (for
6 all mitigation frequencies see Appendix A, Table A17).

Figure 2: The mean number of mitigation requirements $\pm$ SE per plant included in the database aggregated by HUC2 region (left panel) and state (right panel). Regions and states with fewer than ten plants omitted for clarity. The mean and SE for the US were calculated using all plants in the database.

3.1.1 Biodiversity

The Pacific Northwest (3.5, SE=0.3) HUC2 region and state of Washington (4.1, SE=0.4) had the highest mean number of biodiversity requirements per plant (Figure 2). The California (93%) HUC2 and the state of Michigan (97%) had the largest percentages of plants required to implement biodiversity mitigation (Figure 3). Across all HUC2 regions, tier two classified terrestrial biodiversity mitigation was more common than aquatic biodiversity mitigation (Appendix A, Figure A7), and illustrated with the most common types of biodiversity mitigation: terrestrial species conservation/management/monitoring (required at 42% of plants), terrestrial wildlife or habitat management (29%), and aquatic species conservation/management/monitoring (25%).

Biodiversity mitigation appears more common among Western, Midwestern, and Southeastern US hydrologic regions and states. The high proportion of protected federal lands in the western portions of the US, patterns of spatial biodiversity and endemism within the US (Jenkins et al. 2015), plant characteristics, or socio-political factors (Kosnick, 2010) are possible influences for this trend. To promote more sustainable operation of the US hydropower fleet, data linking biodiversity mitigation actions and outcomes with biodiversity needs at varying spatial scales would be useful.

Figure 3: The percentage of plants in the database with mitigation requirements by Tier 1 mitigation classifications, aggregated by HUC2 region (left panel) and state (right panel). Percentages less than 90% are labeled. The numbers of plants per HUC2 region and state are in parenthesis. Regions and states with fewer than ten plants omitted for legibility.

3.1.2 Fish Passage

The New England (3.3, SE=0.4) and Pacific Northwest (3.0, SE=0.4) HUC2 regions, and the states of Washington (4.2, SE=0.6) and Maine (3.7, SE=0.6) had the highest mean number of fish passage requirements per plant (Figure 2). The Pacific Northwest (71%) and Mid Atlantic (69%) HUC2 regions,

1 and the states of New York (89%), Washington (81%), and Oregon (77%) had the largest percentages of
2 plants required to implement fish passage (Figure 3). No plants were required to implement downstream
3 passage within the Alaska, California, or Tennessee hydrologic regions (Appendix A, Figure A7).
4 Upstream passage requirements were absent in a number of regions, but most frequently required in the
5 New England (54% of plants) and Pacific Northwest (37%). The most commonly required fish passage
6 mitigations were: trash racks to prevent fish entrainment (17%), downstream fish passage plans, studies,
7 or designs (16%), and downstream fish passage monitoring (14%).

8 Aquatic habitat fragmentation and fish migration disruption caused by dams are a major driver of
9 ecological risk worldwide (Liermann et al., 2012; Nilsson et al., 2005). Within the US, research on fish
10 passage efficacy at hydropower dams has focused largely on salmonids in the Pacific Northwest, with the
11 bulk of non-salmonid research dedicated to clupeids (herring, menhaden, and shad) in the eastern US
12 (Roscoe and Hinch, 2010; Schilt, 2007). Noonan et al. (2012) indicate that fishway passage efficacies for
13 non-salmonids remain low, owing to passageways designed primarily around commercially important
14 salmonids. Therefore, it is not surprising that the highest proportions of hydropower plants required to
15 implement fish passage were observed in the Pacific Northwest, Mid-Atlantic, and New England regions,
16 regions with populations of salmonids or clupeids. Importantly, fish passage requirements are relatively
17 infrequent in the Missouri, Upper Mississippi, and Ohio basins, where dams and hydropower facilities
18 play a critical role in the population dynamics and habitat connectivity of freshwater, large river species
19 such as paddlefish and sturgeon (Pracheil et al., 2014; Tripp et al., 2014). Similarly, low rates of fish
20 passage requirements occur in the South Atlantic-Gulf and Tennessee basins despite high rates of fish
21 species richness and endemism (Jenkins et al., 2015). In regards to the broad scale sustainability of the US
22 hydropower fleet, this assessment suggests that there is significant room to consider non-salmonid
23 passage needs for fish within central and southeastern US hydrologic regions. Moreover, we observed a
24 much lower proportion of hydropower plants in both the Alaska and California hydrologic regions
25 required to implement fish passage mitigation compared to the Pacific Northwest. This was not

1 anticipated given that salmonid species are found within all three regions. This might be due to different
2 listing statuses of distinct populations of salmonids within each region or the lack of suitable habitat
3 either upstream or downstream of particular projects. While the underrepresentation of California plants
4 might contribute to this finding, it also highlights a need for future research to explore fine scale
5 independent variables that might contribute to particular types of mitigation being required such as high
6 resolution species distribution or abundance data, upstream and downstream habitat quality indicators,
7 and socio-political factors.

8 *3.1.3 Habitat*

9 The Pacific Northwest (1.7, SE=0.2) and the Missouri (1.7, SE=0.3) HUC2 regions, and the states of
10 Alabama (2.5, SE=0.4) and Washington (2.4, SE=0.4) had the highest mean number of habitat
11 requirements per plant (Figure 2). The Tennessee (100%) and Missouri (86%) HUC2 regions, and the
12 states of Michigan (97%) and North Carolina (93%) had the largest percentages of plants required to
13 implement habitat mitigation (Figure 3). The most frequent habitat mitigation requirements were invasive
14 aquatic plant management (20%), shoreline management plans (17%), and woody debris management
15 (15%). Generally there appears to be an emphasis on reservoir habitat for plants in the South-Atlantic
16 Gulf, Tennessee, Mid Atlantic and Upper Mississippi region whereas the western regions have higher
17 frequencies of riparian and fisheries habitat mitigation (Appendix A, Figure A7).

18 The objectives of these habitat mitigation requirements are not as well defined as other categories,
19 since habitat protection may indeed contribute to water quality improvements, biodiversity protection, or
20 just the protection of geophysical features. Importantly, these types of habitat management and restoration
21 efforts are a portion to the substantial ecological restoration economic sector (BenDor et al., 2015) that
22 has largely lacked adequate project assessments, monitoring, and tracking (Bernhardt et al., 2005).
23 Sustainable development of hydropower resources will require quantifiable understanding of ecological
24 responses to mitigative efforts (Jager and Smith, 2008); therefore, linking ecological outcomes to habitat
25 mitigation and restoration efforts outlined in FERC licenses should be a priority for future investigation.
26 Many habitat mitigation requirements require that annual reports on project progress and outcomes be

submitted to FERC. Future efforts should link objectives and outcomes outlined in these reports with the requirements in the current mitigation database to provide a better understanding of the effectiveness and costs of mitigation requirements.

3.1.4 Hydrologic Mitigation

The Alaska (4.2, SE=0.5), and California (4.0, SE=0.4) HUC2 regions, and the states of Massachusetts (4.8, SE=0.6) and North Carolina (4.3, SE=0.6) had the highest mean number of hydrologic requirements per plant (Figure 2). The Tennessee (86%) and Great Basin (61%) HUC2 regions, and states of Montana (88%) and Utah (55%) were the only regions and states where less than 90% of plants were required to implement hydrologic mitigation (Figure 3). Moreover, 82% of 447 plants in the database were required to provide minimum flows to a bypassed reach or below a tailrace. Out of the 210 plants with a bypass reach, 96% were required to provide minimum flows, 36% were required to provide minimum flows only within the bypassed reach, 53% were required to provide minimum flows within the bypassed reach and had additional minimum flow requirements below the tailrace (i.e., below the powerhouse discharge), and 7% were required to only provide minimum flows below the tailrace. Most plants throughout the country were required to provide a static year-round minimum flow or to release inflow in either the tailrace or bypass by operating in a run-of-river operating mode. The California hydrologic region was the only area where the majority of minimum flow releases change by season or annual water conditions (Figure 4).

Figure 4: Proportion of all minimum flow requirements for plants in the database aggregated by HUC2 region and state. HUC2 regions and states with fewer than ten plants omitted for legibility. The ordering of minimum flow requirements does not imply increasing or decreasing environmental benefit.

Non-minimum flow related hydrological mitigation were classified as either flow mitigation (e.g. ramping rate requirements, flushing or flood flows), operations (e.g. providing flow information electronically, compliance plans), or sediment (e.g. sediment and erosion control plans, dredging).

Ramping rate constraints (the rate of changes in flow over a given period of time) and flushing or flood flows provide beneficial effects to stream fish and habitats (Young et al., 2011) and represent components of natural flow variability (Poff, 2009). The geomorphology and habitat in downstream reaches are also impacted where hydropower facilities modify sediment and bedload transport (Grant et al., 2003; Osterkamp and Hupp, 2010). Ramping rate and flood flow requirements were observed infrequently among plants nationwide (Table 3). While sediment and erosion control plans were required at 43% of plants nationally, specific mitigation to reduce sediment behind dams was recorded at less than 2% of dams nationally (Appendix A, Table A17).

Table 3: Frequency of ramping rate and flood or flushing flow requirements.

Hydrologic mitigation	Section	Plants without bypass (n=210)	Plants with bypass (n=237)
Ramping rate	Bypass only		10%
	Tailrace only	12%	8%
	Bypass and tailrace		2%
Flood flow	Bypass only		10%
	Tailrace only	2%	1%
	Bypass and tailrace		<1%

The licensing process appears to place a high importance on minimum flows, as 82% of plants require some type of minimum flow requirement in tailraces or bypassed river reaches. Comparatively, Sale et al. (1991) found minimum flow requirements at only 56% of hydropower projects licensed from 1980 to 1990, indicating an increase in minimum flow requirements within project licenses. Out of 447 hydropower plants, 80 did not include minimum flow requirements. Eighteen of the plants without minimum flows were non-federal hydropower facilities added to existing federally owned and operated dams where downstream flow releases are already controlled by a federal agency. Seven plants were municipal water conduits, canals, or irrigation projects that may or may not release water downstream. Eight of the plants were part of a larger project with existing coordinated flow releases not documented within the license. Three of the plants were pumped storage facilities without downstream discharges.

1 Among remaining plants, target annual minimum flows or run-of-river operation were most frequent.
2 Although target minimum flow releases represent a practical method to protect environmental flows,
3 combined with the low frequency of flood or flushing flows and ramping rate requirements, they may not
4 reflect enough of the natural flow variability required to meet ecologically sustainable goals (Richter,
5 2010; Richter et al., 2012) and can contribute to homogenization of flow regimes, biodiversity, and
6 ecosystems (Poff et al., 2007). Run-of-river operations, on the other hand, require hydropower plants to
7 release flows closely matching impoundment inflows with intent to protect downstream aquatic resources.
8 Run-of-river operation does not guarantee restoration of natural flow regimes because upstream dams and
9 hydropower facilities might operate as storage or peaking facilities (Jager and Bevelhimer, 2007). An
10 increase in the frequency of minimum flow releases based on season or on shifting annual flow
11 requirements set by water managers is observed in the western US. While these minimum flows reflect
12 variability in seasonal and annual flows, it is not clear if they meet ecological goals or are simply a
13 byproduct of the political process that is part of setting minimum flows (Jager and Smith, 2008). Missing
14 from these broad scale minimum flow requirements are data on actual flow releases, as well as ecological
15 responses that can be used to evaluate and optimize flow releases with environmental, societal, and
16 energy production objectives (Jager and Bevelhimer, 2007; Jager and Smith, 2008; Poff, 2009).

3.1.5 Recreation

17 The Tennessee (4.4, SE=0.4) and South Atlantic-Gulf (4.2, SE=0.5) HUC2 regions, and the states of
18 Alabama (4.9, SE=0.8) and North Carolina (4.9, SE=0.6) had the highest mean number of recreation
19 requirements per plant (Figure 2). The Missouri (64%), Alaska (50%), and Great Basin (31%) HUC2
20 regions, and the states of Alaska (50%) and Utah (18%) were the only regions and states where less than
21 70% of the plants were required to implement any recreation measures (Figure 3). The most frequent
22 recreation requirements were recreational management plans, studies and monitoring (74% of plants), day
23 use area improvements (36%), and parking (28%). That approximately 82% of plants contain recreation
24 requirements highlights the importance that FERC licenses place on beneficial public uses of project
25 lands and waters. Recreational flow requirements make up a small portion of all recreational

requirements. Approximately 9% of plants nationally are required to provide downstream recreational flows (either for whitewater boating purposes, fishing, or general boating) and approximately 4% are required to maintain flows to provide for lake-based recreation.

3.1.6 Water Quality

The Ohio (1.7, SE=0.4) HUC2 region and the state of Michigan (3.6, SE=0.2) had the highest mean number of water quality requirements per plant (Figure 2). The Ohio (90%) and the Pacific Northwest (75%) HUC2 regions, and the states of Michigan (100%) and Oregon (95%) had the largest percentages of plants required to implement water quality mitigation (Figure 3). We identified 25 different water quality parameters included as part of water quality monitoring requirements. Dissolved oxygen (DO, 40% of plants) and temperature (37%, Appendix A, Figure A8) were the most frequently required water quality monitoring parameters leading to downstream water quality monitoring plans (48%), impoundment water quality monitoring plans (16%), and inflow water quality monitoring plans (9%) as the most commonly ordered water quality mitigation.

Although nearly half of the plants in the database are required to monitor downstream water quality, we were surprised at how few are required to implement specific water quality mitigation technologies (such as weirs, aerators, or operational changes). For example, 40% of plants in the database have DO monitoring requirements but only 8% of plants in the database reference specific DO mitigation technologies. Similarly, in a review of DO mitigation requirements in 300 FERC project records issued after 1986, EPRI (2002) found 40% of licenses contained DO requirements but only 3% contained specific technology requirements. The high frequency of monitoring suggests that water quality impacts from hydropower operations are a concern. However, the low frequencies of specific water quality mitigation technologies might be attributed to the numerous factors that contribute to water quality outside of the traditional hydropower project boundary including; land-use changes (Brown and Froemke, 2012; Martinuzzi et al., 2014), non-point source pollutants, water withdrawals and discharges, and changes in river morphology (Nilsson and Renöfält, 2008). Multi-scale spatial assessments of these landscape disturbances can assist in the identification and evaluation of factors contributing to water

quality or habitat decline as well as the evaluation of possible management strategies (Esselman et al., 2011). Linking these landscape disturbances with spatial approaches to assess environmental impacts and benefits of hydropower development provides an approach that can identify scenarios in which water quality can be sustainably addressed (Brown et al., 2009; McManamay et al., 2015). Assessing the potential of hydropower mitigation to address water quality will require additional data mining and analysis to link data collected on the ecological outcomes from hydropower mitigation. While our database indicates FERC and state agencies have often required water quality monitoring, these results remain fragmented among individual reports filed to FERC and state water quality agencies.

3.2 CHALLENGES

The utilization of FERC licenses to collect mitigation information presents certain challenges to collating mitigation information and should be kept in mind when interpreting results. First, the database is an exhaustive survey of mitigation included in licenses issued from 1998-2013 and does not include mitigation not found within the surveyed licenses. Therefore, it is important to consider that mitigation measures, such as climate change mitigation (van Vliet et al., 2016; Viers, 2011), might remain available but are not included the database.

Second, plant relicenses may not include previously required mitigation. For example, an existing hydropower plant may already have an operating fish ladder. Upon relicense, the FERC issued license might not include the fish ladder in the license articles. Often times in this situation, operating plans, monitoring, or modification to existing structures are required. Therefore, in many cases we are still able to capture aspects of existing mitigation.

Third, FERC encourages the use of settlement agreements (legal agreements developed between hydropower developers, agencies, and other stakeholders on project operations and environmental conditions) that may include mitigation not included in the final license. FERC does not include “off-license” mitigation if there is an unclear connection between the mitigation and project impacts, the mitigation is unenforceable by FERC, or there is a lack of evidence provided during licensing to support

1 the mitigation requirement (FERC, 2006). In these cases, mitigation implemented by the developer is not
2 documented within the FERC license and was not captured in the database because we restricted our
3 searches to the licenses themselves.

4 A final challenge in the interpretation of results was the high occurrence of ‘plans, management, and
5 monitoring.’ These mitigation types require the licensee to develop and submit plans for mitigative action
6 in coordination with regulatory agencies or as part of an adaptive management action. Therefore, specific
7 mitigative might not be developed and implemented until well after the license is issued. The high
8 frequency of these actions might indicate a tendency of FERC to allow hydropower licensees to develop
9 specific mitigation measures after the initial license is issued instead of prescribing specific mitigation
10 technologies in the license and may also reflect the difficulty in resolving the sometimes highly
11 contentious expectations amongst different stakeholders.

12 The value of the database would be enhanced with future updates that include mining earlier licenses,
13 environmental impact statements, post-licensing plan submissions, and settlement agreements to capture a
14 comprehensive picture of existing mitigation requirements at hydropower facilities. Lastly, inclusion of
15 the outcomes included in reports and studies submitted to FERC would aid efforts in linking multi-scale
16 ecological outcomes with hydropower operation and mitigation.

17 4. CONCLUSIONS

18 The primary objectives of this project were to collate FERC mitigation requirements at non-federal
19 hydropower plants into a searchable database and provide a broad scale assessment of mitigation
20 requirements across the US. Our results present trends in FERC mitigation requirements across the US
21 and indicate that a wide range of opportunities exist to address flow regimes, water quality, and fish
22 passage at hydropower dams. According to Jager and Smith (2008) current management perspectives on
23 hydropower management require the incorporation of ecological values and quantifiable understanding
24 between flow variation and ecological outcomes. For these data to be ultimately useful in the sustainable
25 planning of hydropower resources, linking these mitigation requirements to ecological responses is

1 required. Combining mitigation requirements with evaluations of the effectiveness of mitigation could
2 feed into decision making frameworks intended to optimize both hydropower production and
3 environmental protection.

4 The data collection process highlighted that although much of the needed information is available
5 through FERC's e-Library information portal, key information on mitigation implementation, planning
6 and monitoring results, and mitigation efficacy remains highly fragmented. Using these data for planning
7 and meeting hydropower sustainability targets will require a central repository for all data related to the
8 relicensing process from the license application filling to mitigation implementation and monitoring. In
9 order to maximize the database's usefulness, future updates should be planned to incorporate new license
10 information, coordinate with mitigation cost estimates, and evaluate effectiveness of mitigation
11 implementation.

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