



Winter 2008

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### Recommended Citation

Brett D. Crow, *Equal Consideration and Systematic Measurement Error in Hydroelectric Relicensing*, 48 Nat. Resources J. 91 (2008).

Available at: <https://digitalrepository.unm.edu/nrj/vol48/iss1/5>

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# Equal Consideration and Systematic Measurement Error in Hydroelectric Relicensing

## ABSTRACT

*Several familiar environmental effects of hydroelectricity production are examined using stylized data derived from a Federal Energy Regulatory Commission analysis for a project under relicensing consideration. The data set reveals systematic measurement errors that can be explained by a failure to consistently assume a single license denial storage regime (empty reservoir, full reservoir, partly full reservoir, or current storage with turbine bypass) when determining the effects of continued operation. One interpretation of these errors is that beneficial effects of license renewal are generously measured, while harmful effects are restrictively measured despite a legal requirement for equal consideration.*

## I. INTRODUCTION

Hydroelectric power generation is considered by some to be a clean electricity source that provides many benefits including abundant recreational opportunities. Others consider this particular power source to be one that produces considerable environmental damage. Such perceived impacts can easily clash in the process of relicensing hydroelectric generation facilities. This relicensing process, conducted by the Federal Energy Regulatory Commission (FERC), provides a method for evaluating and addressing the effects of continued operation of existing hydroelectric power plants. Approximately 1,000 such facilities currently operate in the United States under licenses issued by FERC. Approximately half of these licenses are set to expire by the end of the decade.<sup>1</sup> Evaluating the operation of a hydroelectric power plant requires considering a broad spectrum of environmental consequences. Furthermore, the Electric Consumers Protection Act of 1986 (ECPA) requires FERC to afford "equal consideration" to

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1. David A. Harpman, *Assessing the Short-Run Economic Cost of Environmental Constraints on Hydropower Operations at Glen Canyon Dam*, 75 LAND ECON. 390, 390 (1999); Michael R. Moore et al., *Testing Theories of Agency Behavior: Evidence from Hydropower Project Relicensing Decisions of the Federal Energy Regulatory Commission*, 77 LAND ECON. 423, 440 (2001).

energy conservation, fish and wildlife, recreational opportunities, and other aspects of environmental quality.<sup>2</sup>

Analyzing the effects of hydroelectric relicensing in dollar terms is difficult because of the variety of environmental goods, services, and amenities involved. These challenges may help explain why economists have documented absent and inaccurately used economic information in FERC analyses and utilized methods that increase the apparent expense of proposed mitigation measures.<sup>3</sup> For example, FERC neither relies on nor tends to use non-market valuation methods in its environmental benefit assessments.<sup>4</sup> Loomis et al. assert that failure to use such methods "often results in an implicit value of zero being placed on ecosystem services."<sup>5</sup> On the other hand, Stephenson and Shabman observe that strong evidence of detrimental environmental outcomes in hydroelectric relicensing has yet to appear.<sup>6</sup>

At the same time, it can be difficult to convince policy makers and scientists from other disciplines to seek and use the results that economists can develop. FERC is not required to conduct social benefit-cost analyses when relicensing hydroelectric facilities and may view such studies as overly difficult.<sup>7</sup> Stephenson and Shabman suggest a low demand for non-market valuation studies by relicensing participants. They also observe that "most analysis is focused on quantifying ecosystem changes in terms familiar to the decision participants."<sup>8</sup>

This article uses fundamental economic and statistical concepts to examine a small set of stylized environmental data derived from a hydroelectric relicensing analysis conducted by FERC. The benefits of this approach are threefold. First, framing the problem in this way may improve communication between economists, policy makers, and other scientists. The reach of economic thought in hydroelectric relicensing might then be extended beyond benefit-cost analysis and value measurements in dollar terms. Improved interdisciplinary collaboration may result by presenting an economic view that directly relies on measurements recorded in a

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2. Electric Consumers Protection Act of 1986, § 3(a), 16 U.S.C. § 797(e) (2000).

3. Moore et al., *supra* note 1, at 427, 429.

4. Kurt Stephenson & Leonard Shabman, *The Role of Nonmarket Valuation in Hydropower Relicensing: An Application of a Pattern Modeling Approach*, 35 J. ECON. ISSUES 497, 502 (2001); Moore et al., *supra* note 1, at 427.

5. John Loomis et al., *Measuring the Total Economic Value of Restoring Ecosystem Services in an Impaired River Basin: Results from a Contingent Valuation Survey*, 33 ECOLOGICAL ECON. 103, 104 (2000). The context of this study was river-based, not hydroelectric relicensing.

6. Stephenson & Shabman, *supra* note 4.

7. John Loomis & Marvin Feldman, *An Economic Approach to Giving "Equal Consideration" to Environmental Values in FERC Hydropower Relicensing*, 5 RIVERS 96, 97 (1995); Moore et al., *supra* note 1, at 427.

8. Stephenson & Shabman, *supra* note 4.

fashion familiar to other scientists. Second, apparently conflicting views of continued hydroelectric power generation can be more clearly understood, explained, and reconciled to some degree by the following analysis. Third, the small set of familiar data values reveals systematic measurement errors that raise serious questions about FERC's pursuit and attainment of its equal consideration mandate. Such errors can be explained by a failure to apply a uniform measurement standard to all environmental measurements.

Section II presents and analyzes a set of stylized data. The analysis finds that quantitative relicensing measurements assume that license denial will result in the end of hydroelectric power generation. However, this does not necessarily imply that water storage will also end, and the water storage regime greatly affects the positive and negative effects that will result from license denial. As a result, the examined measurements are each correct under a specific license denial storage regime and incorrect under other potential regimes.

The analysis then tabulates the data set observations under four specific license denial storage regimes and finds both systematic measurement errors and statistical confounding in the data set. Section III presents a method of coding the tabular summary so that it can be applied beyond the stylized data set. That presentation seeks and indirectly expresses systematic measurement errors, directly expresses the measurements of other scientists based on their units of choice, and provides an economic view in one market where positive and negative externalities exist. The explanations, table, and data codes permit interdisciplinary study of the experimental design and data treatments that inform relicensing decisions and shed light on the type of policy statement needed to give all scientists a single measurement baseline. In addition, the article shows how environmentally based subsidies can rest on the use of systematically different measurement standards for beneficial and harmful effects if policy is not clear and rigorously enforced. Section IV concludes the article with experimental design reflections and policy implications taken from the analysis.

## II. ANALYSIS OF STYLIZED FERC DATA

This article's analysis is based on a relicensing process conducted by FERC in the western United States. The relicensing process incorporates data developed by scientists from a variety of particular disciplines. These data were submitted for public comment by FERC as either a draft or final environmental impact analysis within the past several years. All examined data values concentrate on the reported effects of continuing to operate the hydroelectric facility within a reservoir-based geographic boundary between the lowermost river mile location of a dam that provides the

inundation opportunity and the uppermost river mile location that is inundated by a full reservoir.

Within that boundary, the article considers a project that typically produces 1,500 gigawatt-hours (GWh) of electricity per year and provides 100,000 annual visitor-days of reservoir-based recreation. The article sets aside the inherent variability of such measurements and their tendency to change over time and therefore uses the word "typically" to convey the statistical concept of central tendency in an elementary form such as mean or median. In addition, the recreation figure may be regarded as an actual count, as if reservoir users passed through a turnstile, or as an estimate reached through proper sampling procedures. Continued operation of this project also prevents the recovery of dry land habitats such as those that might be used by rabbits or deer on 2,000 acres of potentially dry land, as measured from a reservoir that holds 25 percent of its total capacity. In other words, a long-existing reservoir at 25 percent of its capacity reveals barren slopes above the corresponding water level, up to an elevation marked by high water reservoir detritus and the resumption of dry land habitats at the reservoir's filled level. The 2,000 acres figure measures this land area on both sides of the low-storage reservoir. Finally, project operations obstruct recoverable fish passage throughout a filled reservoir length of 30 river miles.

These particular measurements are stylized data values derived from the FERC document through a process of arbitrary scaling. None of the above measurements actually appear in the FERC document. The preceding paragraph and subsequent references to these measurements are otherwise accurate in the sense that each stylized measurement can be replaced with its actual corresponding value from the FERC document. The data values have been stylized in this way to render the actual project anonymous and to emphasize the generality of this article's analysis. Two particular facts from the FERC document, however, are not stylized and have not been altered. This is done because zero values cannot be scaled up or down. First, the agency did not report any effect of continued operation of the hydroelectric project on recreational river use within the reservoir-based geographic boundary. Assuming that river-based recreational uses are sufficiently scarce that gaining or losing some of them would be valuable, this article regards FERC's failure to report a river-based recreation quantity as the sensible act of not reporting a measurement that is actually zero. Second, some hydroelectric facilities do provide fish passage opportunities with mechanisms such as fish ladders, whose efficacy can be measured or debated. Neither exists at the facility examined in this particular FERC document. That is, the project analyzed by FERC either

contains no fish passage mechanisms or the provided mechanisms are completely ineffective.<sup>9</sup>

In summary, this article asks readers to consider FERC's official reporting regarding the effects of continuing to operate a hydroelectric project that has existed long enough to warrant relicensing consideration within the project's reservoir-based geographic boundary. Stylistically, operating this project provides 1,500 GWh per year of electricity and 100,000 visitor-days per year of reservoir-based recreation. Also, recoverable dry land habitat is foregone on 2,000 acres of land revealed by a reservoir at 25 percent of its capacity, and fish passage is prevented on a filled reservoir length of 30 river miles. Accurately, fish passage measures at the facility are either nonexistent or ineffective, and the failure to report any effect on river-based recreation is regarded as indicating a zero quantity measurement for recreational opportunities that are indeed valuable.

This article now proceeds to show that statistical confounding and systematic measurement error plague this small set of familiar operating effect measurements: whenever at least one of the four external effect measurements is actually correct, then at least two of them are incorrect.

### **Hydroelectric Operating Effects and License Denial Storage Regimes**

The argument begins with the most obvious and direct effect of continuing to operate the project—the annual provision of 1,500 GWh of electricity. This quantity is clearly measured from zero annual gigawatt-hours, a figure that is central to the nature of the measurement. Statistically, the 1,500 GWh per year figure is a quantitative data value, so that ordinary arithmetic operations and number line representations are sensible. Mathematically, the measurement's number line representation is a line segment with two specific endpoints. This is true because the measurement is both finite and nonzero. One of these endpoints is zero, which represents the end of the project's electricity production upon license denial, and the other endpoint is 1,500 GWh per year, which represents the effect of continuing to operate the project in its current fashion.

These statements contain important information about properly measuring the effects of continuing to operate an existing hydroelectric project in two particular ways. First, standard texts that introduce experimental design observe that the effects of a given treatment are

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9. The arbitrary scaling of cardinally measured data values is valid because the article's argument is ordinal in nature. That is, the FERC document records all miles of fish passage obstructed by a full reservoir and all annual visitor-days of reservoir-based recreation. It records some recoverable dry land acreage based on a reservoir that is partially filled, and it does not record any recoverable visitor-days of river-based recreation. The article retains this rank ordering, even as the scaling process alters the cardinal measurements themselves.

measured by comparison to the treatment's absence.<sup>10</sup> In this scenario, treatment is the act of continuing current power generation practices, and treatment absence is the potential end of that power generation via license denial.<sup>11</sup> In other words, the number line representations of quantitative relicensing measurements span the gap between one endpoint that represents ending generation via license denial and a second endpoint that represents continuing current power generation practices. Economists, in particular, will recognize the familiar prospective form of with and without thinking: 1,500 GWh per year of electricity will be provided if current generation practices continue and 0 GWh per year will be provided if a license is denied and the project's generation ends. Mathematically, it is correct to observe that 1,500 GWh per year of electricity will be provided if generation continues and the project's 1,500 GWh per year of electricity will be foregone if license denial ends electricity generation. These parallel observations reflect the fact that number line distances do not vary with the direction of measurement.

Second, these statements specifically avoid potential confusion with the project's original licensing and construction. Data values relevant for that social choice question involve a treatment that consists of the onset of hydroelectricity production and an absence of treatment that consists of a failure to begin hydroelectricity production. This differs from the social choice question of relicensing, where the treatment is continued electricity production and the absence of treatment is the potential end of electricity production through denial of a license. In particular, relicensing data values are not retrospective and do not entertain counterfactual project absence. Measuring existing electricity production from a zero value that represents not having constructed a hydroelectric project, for example, produces a measurement that is cumulative, historical, and retrospective in nature. Such measurement is based on the false premise of never having constructed and operated a project whose continued use is being contemplated. Instead, relicensing data values recognize the current existence of a hydroelectric project, including the presence of a dam and water storage regime, and posit the potential end of hydroelectric power generation.

Throughout, this article adheres to the economist's prospective view of continued generation effects and the statistician's continued generation (treatment) versus ending generation via license denial

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10. See, e.g., DAVID S. MOORE & GEORGE P. MCCABE, *INTRODUCTION TO THE PRACTICE OF STATISTICS*, 200-02 (5th ed. 2006).

11. Other means of not generating electricity, such as a terrorist attack or temporary maintenance shutdown, are not relevant to relicensing analyses because the simplest relicensing question merely concerns granting a new license or not doing so.

(treatment absence) approach. This avoids both potential confusion with original project construction and entertaining counterfactual project absence and helps provide a uniform footing for all measurements. It also means that license denial is not a separate and distinct option relative to granting a new operating license. Instead, potential license denial is an unavoidable and integral part of the very measurements that inform relicensing decisions because considering potential license denial is one endpoint of the number line intervals that represent the measurements. The fundamental nature of quantitative relicensing measurements is a set of measurements that record beneficial effects, which support a renewed operating license, and harmful effects, which suggest or indicate mitigation measures and weigh against license renewal.<sup>12</sup> Whether beneficial or harmful, however, all nonzero quantitative measurements have number line representations that reflect prospective license denial as one endpoint and the continuation of current generation practices as the other endpoint.

Based on the measurement foundation set out above, this article will now examine the project's external effects, beginning with the stylistically reported provision of 100,000 annual visitor-days of reservoir-based recreation. This measurement indicates that 100,000 visitor-days per year will be provided if current operations continue and zero visitor-days per year will be provided if license denial ends electricity production. That is, the entire 100,000 visitor-days per year quantity will be lost by license denial if continued hydroelectricity production alone provides all of these recreational opportunities. (The FERC document admits this potential loss.) These measurement observations initially raise the question of how license denial might result in zero reservoir visits. One possible explanation is that license denial would mean storing so little water that all potential reservoir users voluntarily refrain from reservoir use, perhaps due to the very small water quantity and an unattractive basin of barren slopes or extensive muddy flats. A second potential explanation is that a larger water quantity would remain, so that potential users would use the reservoir if permitted. However, usage would be denied in a fashion that produces zero reservoir visits, such as fencing or security patrols. In either case, the 100,000 visitor-days per year figure, if correct, must be measured from zero annual visits. The ways zero visits might occur raise the question of how water storage would proceed at a reservoir site if a new operating license is denied. The

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12. This is the essential framework of a benefit-cost analysis. License denial is indicated when harmful effects outweigh beneficial effects unless operational changes or mitigation measures can reverse the imbalance. Granting a new license is indicated when the reverse applies, in which case operational changes or mitigation measures may be able to increase the positive difference between beneficial and harmful effects. Either case will entail tradeoff analysis, which this article does not consider. Instead, this article only addresses the proper collection of data that accurately inform subsequent tradeoff analyses.



potential answers to that question form the foundation of this article's arguments about systematic error and statistical confounding in FERC's consideration of these effects.

The essential steps to initiating hydroelectric power generation are constructing a dam, storing water, and directing water through turbines. Relicensing measurements necessarily consider the potential end of electricity production, but this statement alone says nothing about the continued presence of a dam or continued water storage. The last step is addressed because failure to generate electricity means not directing water through turbines. But, will water storage continue and, if so, in what fashion? Will a dam remain or not? This article will now proceed to demonstrate that consistently addressing these water storage questions is crucially important in order to avoid confounding the effects of continued water storage with the effects of continued power generation. Furthermore, the dam question is almost a technical afterthought, similar to neglecting the period at the end of a sentence.

Specifically, consider the following four water storage options if a new license is denied and electricity generation ends: an empty reservoir site, a partly full reservoir held at some constant level, a reservoir whose level fluctuates as it did before ending electricity generation, and a reservoir that is constantly full. These four options nearly exhaust the possibilities for water storage in the event of license denial, since the only remaining option is a reservoir with a varying level and fluctuation characteristics different than those observed when generating electricity. That option is set aside and is not discussed in this article due to its breadth and unpredictability. The first four options are investigated, however.

Initially, consider the option in which license denial ends electricity production, but a reservoir operator continues a pattern of reservoir fluctuations that matches the fluctuation pattern of prior electricity production. More precisely, license denial would mean bypassing turbines while maintaining all other storage and release attributes that currently characterize electricity production. The text refers to this option as either Turbine Bypass or  $0_{\text{Current}}$ .<sup>13</sup> If this is the water storage meaning of license denial, then it is correct to observe, albeit roughly, that continuing to

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13. The  $0_{\text{Current}}$  designation is used in the following section. It conveys the notion that the potential end of electricity production via license denial represents the absence of the power production treatment by way of bypassing turbines but otherwise maintaining current storage and release practices. It also conveys the notion of a specific operating effect baseline or specific measurement standard—a zero or standard reference point from which operating effects are measured.

generate electricity does not provide any reservoir-based recreation.<sup>14</sup> Instead, all of the recreational visits are provided by the continued presence of stored water. Economically, this is because reservoir users are indifferent about whether or not electricity is generated when water is released from a reservoir. Therefore, reservoir usage will stay more or less the same if the only water storage consequence of license denial is the end of electricity production by way of bypassing turbines. Statistically, this is because the effect of continued water storage has been completely separated from the effect of continued power generation. The statistical source of the systematic measurement errors discussed herein is a failure to uniformly separate these two sources of effects commonly attributed to hydroelectricity production. Such confusion leads to confounding.

Next, consider the opposite extreme in which continued water storage effects and continued power generation effects are not separated at all. Instead, the effect of continued water storage is completely combined with the effect of continued power generation, so that all 100,000 visitor-days per year are viewed as originating from the sole circumstance of continued power production. This is precisely what occurs if the end of electricity production via license denial means the end of water storage at the reservoir site. In that case, then, the Empty Reservoir baseline or  $0_{\text{Empty}}$  measurement standard applies. In other words, zero annual reservoir visits will occur if license denial means the end of water storage at the reservoir site, and 100,000 visitor-days per year will occur if current power generation practices continue. Therefore, it is correct to observe that the sole circumstance of continued power production provides the entire annual quantity of recreational visits.<sup>15</sup>

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14. The "roughly" qualification addresses the fact that license denial at an existing hydroelectric facility is likely to prompt a change in the price of electricity when electricity is procured from a different generation source. The article does not address this complication, which is an empirical matter that requires the use of more extensive economic analysis. Instead, the article assumes that quantities potentially affected by electricity price changes are actually unaffected by such changes. In economic terms, reservoir-based recreation is assumed to be perfectly inelastic with respect to electricity price changes.

15. It is important to correctly understand this logical point, which repeatedly arises in the relicensing problem. If license denial means the end of water storage, then the entire annual recreation quantity will be lost. The converse, however, is not necessarily true, because the entire annual quantity can be lost in ways other than ending water storage. Thus, the potential loss is a necessary but not a sufficient condition regarding the end of water storage. This potential loss does not imply use of the Empty Reservoir baseline or the  $0_{\text{Empty}}$  measurement standard. While bearing this logical point in mind, however, the text otherwise presumes that license denial reservoir usage, if sought, would be permitted. The contrary presumption is not mentioned in the FERC document and, if license denial entails reservoir usage denial, one would expect the document to observe that continued project operation avoids any costs associated with preventing reservoir usage under license denial.

Between these two extremes rests the Partly Full reservoir baseline or  $O_{\text{Low}}$  measurement standard, which partially separates continued water storage and continued power generation effects. This represents a license denial setting in which a reservoir operator would hold a reservoir at some constant level that is neither full nor empty by storing and releasing water as needed. This leads to the discussion proceeding with the stylized 25 percent capacity figure derived from the FERC document. It is therefore reasonable to suppose that ending power generation means that some reservoir visits, perhaps 30,000 visitor-days per year, will occur. In that case, then, the 100,000 visitor-days per year figure is divided into 30,000 visitor-days per year that are provided by continued water storage and 70,000 visitor-days per year that are provided by continued power generation.

Finally, the fourth water storage option under license denial is the maintenance of a full reservoir, which is referred to as the Full Reservoir baseline or  $O_{\text{Full}}$  measurement standard. This license denial storage alternative actually reverses the common understanding that hydroelectricity production provides reservoir-based recreation, because power-producing reservoirs are often not maintained at their full storage capacity. In particular, reservoirs in the western United States typically reach their highest levels after the spring snowmelt and are then gradually drawn down to lower levels during the summer and fall months. This means that the 100,000 visitor-days per year figure is based on a seasonally decreasing reservoir level that would not exist under a full reservoir license denial regime. Instead, license denial would mean ending the seasonal drawdown and leaving the reservoir constantly full so it is reasonable to expect greater reservoir use, perhaps 140,000 visitor-days per year. Thus, the effect of continued power generation on reservoir-based recreation is actually harmful because continued power production provides less of something that society regards as beneficial. Alternatively, the quantity of reservoir-based recreation provided by continued power generation would actually be minus 40,000 visitor-days per year.<sup>16</sup>

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16. The discussion of seasonal drawdowns may prompt the observation that continued power production is annually viewed as a process of partial drainage under the Full Reservoir baseline, hence the harmful nature of continued power generation under this baseline, and is annually viewed as a process of either partial or complete filling under the Partly Full and Empty Reservoir baselines, respectively, hence the provision of positive recreation quantities. Yet one can correctly observe that both filling and partial drainage occur each year. Fiscal years may provide a useful resolution analogy. The project's "fiscal year" under the Partly Full baseline would likely begin in October, in accordance with the Western notion of a water year. Thus, reservoir-based recreation is annually provided by reservoir filling, yet seasonally harmed by a summer drawdown. The project's "fiscal year" under the Full Reservoir baseline would likely begin in June or July, at the end of the spring snowmelt. Thus, reservoir-based recreation is harmed annually because of the seasonal drawdown. This emphasizes the need to precisely specify a baseline for relicensing measurements.

In summary, the stylized 100,000 visitor-days per year figure can be viewed in the following ways. The figure is correct if license denial means the end of water storage because all of these visits would be lost. The figure is overstated if license denial means holding the reservoir at 25 percent of its capacity and if usage at that capacity is both permitted and desired. Some usage would then occur at the 25 percent capacity level because of continued water storage and only the remaining portion of the 100,000 visitor-days per year figure can correctly be attributed to continued power production. The figure is also overstated if license denial means bypassing turbines and permitting usage because reservoir usage would then continue more or less unchanged. Setting aside any indirect price effect, the reservoir-based recreation quantity provided by continued power production is actually zero. Finally, the figure is again overstated if license denial means maintaining a full reservoir. Continued power production then harms reservoir-based recreation by its failure to maintain a full reservoir, which is another way of saying that the provided quantity is not positive.

These observations show that the quantity of reservoir-based recreation provided by continued power generation critically relies on the water storage regime expected by the denial of a new operating license. In particular, the Empty, Partly Full, and Turbine Bypass baselines describe potential degrees of separation for effects due to continued water storage and continued power generation, from no separation to complete separation, respectively, and the Full Reservoir baseline actually reverses the common understanding that hydroelectricity production provides a positive quantity of reservoir-based recreation.<sup>17</sup>

At the same time, the issue of whether or not a dam remains upon license denial is of relatively little measurement importance. One explanation for this statement is that virtually all reservoir-based recreation occurs on a reservoir's surface or along its shore. Very little reservoir-based recreation occurs from a dam that provides the inundation opportunity. Indeed, safety concerns may legitimately prompt the prohibition of reservoir use and access from a dam itself. A second explanation is that nearly all of the potential baselines under discussion, with the sole

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17. It may be valuable to again emphasize the distinction between an initial licensing problem, when no hydroelectric project exists, and the relicensing problem, when a hydroelectric project has existed for many years. Constructing a hydroelectric project where none exists often provides reservoir-based recreational opportunities. But nothing about the past onset of hydroelectricity production can be either replicated or influenced by an affirmative or negative relicensing decision that occurs many years later. Continued power production at an existing project only provides beneficial effects or imposes harmful effects to the extent that the effects would change upon ending electricity production under license denial.

exception of the Empty Reservoir baseline, clearly indicate that a dam remains and that it probably remains in its originally constructed form, or very nearly so. Only the Empty Reservoir baseline suggests partial or complete dam removal, and it is important to note that "implies partial or complete dam removal" is inaccurate.

Logically, this is true because a dam is necessary but not sufficient for water storage and because water storage is necessary but not sufficient for hydroelectric power generation. The first observation is true because dams can exist without water being stored. The western United States, for example, contains many reservoirs that at least intermittently run dry, so that not all dams have water stored behind them at all times. The second observation is true for similar reasons: water can be stored without electricity being generated and not all reservoirs are used to generate hydroelectricity. Thus, the idea that license denial can result in an empty reservoir site can be entertained for measurement purposes without implying or specifying partial or complete dam removal. This can be done by simply considering some other way of ending water storage. Possibilities such as diverting water around a standing structure with tunnels, ditches, or pipelines immediately arise. These options may seem frivolous or may be quite expensive, but they cannot refute a logical argument that is based only on the possibility of not storing water behind an intact dam.

When considering the effects of relicensing an existing hydroelectric facility, continued dam presence is unimportant relative to continued water storage. Dams merely provide an inundation opportunity, and the effects of hydroelectricity generation arise almost entirely by taking advantage of that opportunity. That is, consideration of the structure must be separated from consideration of its actual use. The western United States, in particular, has ample historical precedent for and knowledge about the distinction between structures and water use; the region is known for abandoning the former and engaging in long-standing disputes about the latter. In particular, John Wesley Powell recognized water's value to the region in the nineteenth century and the same doubtlessly remains true in the twenty-first century. Failing to make this distinction unfortunately confuses the vault's door with its contents.<sup>18</sup>

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18. It is true, however, that the question of continued dam presence cannot be ignored completely. For example, a benefit-cost analysis based on zero storage if a new license is denied would need to consider either the expense of dam removal or the expense of bypassing an intact structure. Partial or complete removal of the structure is indicated for analytical purposes if it is the less expensive of these alternatives.

### River-Based Recreation Effects

The analysis for the remaining stylized data values from the FERC document proceeds in a similar fashion, beginning with the cited absence of any continued power generation effect on river-based recreation within the reservoir-based geographic boundary. Again, this article regards that absence as the sensible act of not including a zero measurement for recreational visitor-days that are actually valuable. Initially, however, it is important to observe that the river-based recreation under discussion is not equivalent to the river-based recreation given up to initial project construction. River-based recreation prior to project construction occurred at a potential reservoir site so that existing dry land habitats continued to the edge of a flowing river. River-based recreation within the confines of a long-existing reservoir site, when it occurs, takes place in a river environment degraded by the long existence of the reservoir. River-based recreation can easily occur within the geographic confines of an existing reservoir site by simply having a reservoir level low enough to expose some flowing river water above the reservoir's existing elevation and below its filled elevation. Indeed, such recreation is expected. Fishing in moving river water at a geographic location that is sometimes inundated by a filled reservoir is one potential example. Yet dry land habitats will no longer exist along such an exposed river section due to many years of repeated inundation. Instead, river users will observe barren slopes up to a detritus line that marks a reservoir's filled elevation.

Economically, this distinction occurs because the river-based recreation available at an existing reservoir site is an economic substitute for similar recreation activities that were available prior to inundation. Clarifying this point when misunderstood or misstated corrects arguments that valuable attributes of particular locations have been forever lost, either to inundation or some other type of damage. Useful examples exist in Yellowstone National Park's recovery from fire and the absence of wolves and in ecosystem recovery around Mt. Saint Helens. In each case damage or utter destruction was imposed on the system and recovery has now commenced. Recovery brings forth an economic substitute that becomes a better substitute as recovery proceeds; foregone recovery opportunities refer to these substitutes. Concern about giving up recovery opportunities is not equivalent to seeking what might have been.

The FERC document can therefore be regarded as indicating a zero value for recoverable river-based recreation; in other words, license denial would have no effect on the degraded river-based recreational visits that substitute for the river-based recreation available in the absence of project construction. This is precisely what should occur under the Turbine Bypass baseline or  $O_{\text{Current}}$  measurement standard. As was the case with reservoir-based recreation, setting aside indirect price effects means that river-based

recreation will continue as it currently exists if the license denial water storage regime merely entails bypassing turbines so that the effect of continued power generation is zero. The effect is illusory and need not be measured. Under either the Empty Reservoir or Partly Full baselines, however, license denial can be expected to expose more flowing river water during more of the year when compared with the alternative of continued power generation. Thus, recreational activities on flowing river water can be expected to increase upon license denial so that continued power generation prevents some positive quantity of recoverable river-based recreation. FERC's record of a zero value therefore understates a harmful effect of continued power generation.<sup>19</sup> Finally, a Full Reservoir storage regime under license denial would mean that no river-based recreation can occur within the reservoir-based geographic boundary, while some quantity almost certainly occurs under the existing power-generation storage regime. In that case, continued power generation almost certainly provides a positive quantity of this recreation type. Once again, the Full Reservoir baseline reverses the common understanding of a power generation effect.

### **Recoverable Dry Land Habitat**

The analysis for foregone yet recoverable acres of dry land habitat is largely, though not totally, the same. The FERC document stylistically records 2,000 acres of such habitat, which is again an economic substitute for the habitat that would have existed without project construction and operation, and the document connects this acreage to a reservoir at 25 percent of its capacity. In other words, periodic inundation has produced barren slopes along both sides of the reservoir from the elevation of the 25 percent capacity reservoir to the reservoir's elevation when filled. These barren slopes have a surface area of 2,000 acres. Ending periodic inundation of these slopes by holding the reservoir at 25 percent of its capacity under license denial would permit gradual habitat recovery on these acres. FERC

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19. Given the agency's experience with relicensing, the text assumes that the omission of any river-based recreation effect within the reservoir-based geographic boundary was not merely an oversight. Beyond that, there are other valid, yet untenable, explanations for FERC's failure to report any river-based recreation effect within the reservoir-based geographic boundary. FERC may not have distinguished river-based and reservoir-based recreation, but then the reservoir-based recreational quantity is probably overstated because it includes some river usage. Alternatively, it may be that no river use occurs during times of low reservoir storage or that proper sampling procedures failed to reveal any river use. Both explanations appear unlikely. Finally, it may be that some river-based recreation occurs but that FERC, in contrast to this article, regarded this recoverable river use as valueless, in which case it would have been correct to leave this recreation type out of the FERC document. In addition, the discussion of this recreation type also presumes that usage is permitted rather than denied.

has therefore reported an acreage figure that is correct under the Partly Full baseline or  $0_{Low}$  measurement standard.

The figure is understated, however, under the Empty Reservoir baseline because habitat recovery would proceed on additional acres that are inundated below the level of the 25 percent capacity reservoir. These additional recoverable habitat acres have not been measured or considered. Finally, under either the Turbine Bypass or Full Reservoir baselines, any effect on recoverable acres of dry land habitat is illusory and need not be measured. In the former case, habitat recovery would not occur under license denial because reservoir fluctuations would continue, and in the latter case habitat recovery would not occur under license denial because the entire acreage of the full reservoir's floor would be continually inundated. The 2,000 acres figure thus overstates the acreage of recoverable habitat under these baselines because the recoverable acreage is actually zero.

### **Fish Passage**

The final stylistic measurement from the FERC document concerns the admitted prevention of fish passage on a filled reservoir site's 30 linear river miles, where no passage measures exist or existing passage measures are completely ineffective.<sup>20</sup> If license denial means the end of water storage, namely, the use of the Empty Reservoir baseline or  $0_{Empty}$  measurement standard, then this measurement is correct.<sup>21</sup> Necessary and sufficient conditions again arise on this point. The 30-miles obstruction figure is correct if and only if it is measured from zero obstructed river miles because reaching the "30" position on a number line from any position other than zero must produce a length measurement that differs from 30. Zero obstructed river miles would exist had the river never been obstructed, but this is false since no relicensing outcome can undo the historical fact of project construction. Thus, the reported measurement implicitly supposes zero obstructed river miles if a license is denied, which can only occur by entirely freeing the river from existing obstructions or by perfectly overcoming any obstruction that remains. (The FERC document does not suggest providing passage upon license denial if a passage obstacle

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20. On this point, the FERC document does distinguish the passage obstacle length historically imposed by a dam and the passage obstacle length that currently exists because of project operations.

21. The text does not examine zero storage license denial options such as a reservoir-length pipeline that, although possible, appear fanciful. Also, if this is the means of achieving an empty reservoir site, then the obstructed passage length remains constant whether or not electricity is produced, so the influence of continued power production on the obstruction length is zero.



remains.) The measurement is correct if it proceeds from the Empty Reservoir baseline but does not imply use of that baseline because license denial can provide passage, although perhaps not perfectly so, while storage continues. Fish ladders or physical capture and transport are examples. While bearing this logical point in mind, however, the text otherwise presumes that license denial fish passage either would not exist or would not be effective.

With that caveat, the reported 30-miles figure is overstated under all of the remaining baselines. If license denial means bypassing turbines while retaining other current storage and release characteristics, then any passage effects from continued dam presence and continued water storage are entirely separated from passage effects due to continued power generation. The passage problem upon license denial would therefore remain as it currently exists while power is generated. Therefore, the power generation effect is actually zero. If license denial means holding the reservoir at 25 percent of its capacity, then some obstructed passage length will remain after power generation ends and continued power generation only obstructs the remaining portion of the 30 miles. Finally, the measurement cannot be positive if license denial means maintaining a full reservoir. As was the case with the recreation figures, typical power production operations do not leave the reservoir constantly filled, while license denial under the Full Reservoir baseline would entail a constantly filled reservoir. Thus, under that storage regime, fish seeking passage are likely to find a longer reservoir obstacle under license denial than under current power generation practices so that continued power generation actually reduces the obstacle length.<sup>22</sup>

These observations about the external effects of continuing to operate this hydroelectric project are summarized below in Table 1. It should be noted that the observations are subject to the various

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22. These observations raise the issue of fish passage timing, which the FERC document does not relate to the passage obstacle length. For example, certain migratory fish species may attempt passage while a reservoir is at a seasonally low level at a facility with nonexistent or ineffective passage measures. In that case, the obstacle length of a dam and partly full reservoir, relative to an empty reservoir site, will be less than the filled reservoir length because the dam and still reservoir water form the obstacle for any fish species accustomed to passage in moving river water. Also, dams are again relatively unimportant regarding this measurement. A dam whose base occupies 500 feet of river channel length hinders passage on less than one percent of a passage route relative to a ten-mile long reservoir and less than 0.1 percent of a passage route that totals 100 miles. And a dam is necessary rather than sufficient for water storage. Nearly all passage obstacles vanish if water storage is reduced to zero and remain otherwise (excluding license denial alternatives such as a pipeline equal in length to a full reservoir), and a standing structure can be bypassed to address any remaining passage obstacles. Therefore, storage can be set to zero while water and fish pass from one side of an intact structure to the other.

qualifications that have arisen in the text. In particular, the table presumes that recreational use of both the reservoir and exposed river sections within the reservoir-based geographic boundary will be permitted after license denial and that both of these recreational quantities are perfectly inelastic with respect to the price of electricity. The table also presumes that no effective fish passage measures will be implemented following license denial. Finally, aside from the fact that the FERC document connects the 2,000 acres of foregone yet recoverable dry land habitat to the 25 percent reservoir capacity figure, the table indicates the status of each reported measurement under each particular license denial storage regime without implying that FERC's body of scientific work actually uses any one of these particular storage regime baselines.<sup>23</sup> The table immediately conveys the measurement difficulties present in this small set of familiar measurements because no single license denial storage regime contains correct measurements for all four examined external effects.

Statistically, FERC's data record contains multiple systematic measurement errors under all examined baselines. At this article's level of analysis, FERC's data record relating to the effects of continuing to operate this project is incorrect no matter which license denial storage regime is intended.<sup>24</sup>

### Understanding the Systematic Measurement Errors

These systematic measurement errors can be explained as the result of confounding the sources of the measured effects. Thus far this article has entertained three alternative effect sources other than the act of continuing to generate electricity. First, if at least partially effective fish passage measures existed at this project, then it is possible that the effects of continuing these measures could be confounded with the effects of continued power generation. The lack of any effective fish passage measures at this project eliminates the possibility of confounding these effect sources.

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23. Use of a particular baseline will be implied when a measurement is correct under a particular baseline and when nothing other than use of this baseline can produce a correct measurement. Thus, an implication possibility may exist but no implication outcomes were observed in this small data set.

24. Recall that the analysis excludes a license denial storage regime with a varying reservoir level and a fluctuation pattern that differs from current power generation practices. Second, a continuum of Partly Full baselines exists, and only the 25 percent capacity figure is examined. The analysis would be substantially more complex if it posited specific functional relationships between the license denial storage regime and the quantities of provided or foregone goods and services. Third, the analysis abstracts from indirect price effects, which might otherwise mimic certain errors detailed in the table.

Second, the effects of continued dam presence might be confounded with the effects of continued power generation. This article argues, however, that this potential confounding source is of little importance regarding the examined measurements. Dams are thoughtfully located and efficiently constructed, so that a small physical size provides a large inundation opportunity. This means, for example, that little or no reservoir-based recreation occurs from a dam itself, relative to usage that occurs on a reservoir's surface or along its shore, even if such recreation is permitted. Consequently, a recorded recreational use figure arises almost entirely because of the continued presence of stored water rather than the continued presence of a dam. Similar observations can be made about the other examined effects. Considering that these effects are small, this article can safely abstract from effects produced by a dam's continued presence without incurring an important confounding penalty.

This leaves the third and most important confounding source—the continued presence of stored reservoir water and the manner in which that storage proceeds—which is detailed by the companion row at the bottom of Table 1. The Turbine Bypass baseline completely separates the effects of continued water storage from the effects of continued power generation, which is why all of the examined power effect measurements should be zero in that column of the table. If license denial means bypassing turbines while retaining other water storage and release characteristics, then continued power generation is rather benign. Provided or foregone goods and services will continue to exist at more or less constant quantities upon license denial. Therefore, society will gain or lose nearly nothing in the way of external effects by continuing to generate power under a new operating license.<sup>25</sup> At the opposite extreme, the Empty Reservoir baseline does not separate the effects of continued water storage and continued power generation at all. Instead, this baseline fully commingles these effect sources under the single banner of continued power generation. Thus, continued power generation alone provides all of a reservoir's recreational opportunities because license denial would entail the complete loss of those opportunities, and similar observations apply to the other examined effects. The Partly Full baseline falls in between these extremes.

There are also two distinct economic views of the information presented in Table 1. First, each column can be viewed as providing information about production possibilities. In particular, consider the Empty Reservoir baseline and the presented recreational effects. This

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25. Recall that the analysis does not extend to the tradeoff analyses entailed by potential operating changes or mitigation measures. As used here, continued power generation means continuing the activities that characterize existing generation practices, which the FERC document presents as the source of its measured operating effects.

information provides production possibilities information in the same way as the familiar guns and butter production possibilities curve of introductory economics courses. That is, a certain stretch of river miles can and almost certainly does provide both reservoir-based and recoverable river-based recreational opportunities, even when those river miles are currently inundated during much of the year. The FERC document has fully recorded the quantity of reservoir-based recreation that would be foregone under an Empty Reservoir license denial regime by recording those visits as being provided by continued power generation. Yet, if some quantity of reservoir-based recreation is being provided by continued power generation, mainly through the act of continuing to store water, then some quantity of recoverable river-based recreation is almost certainly being foregone because of the continuing inundation. Because the FERC document records no such quantity, it distorts the terms of any subsequent tradeoff analysis. In a Robinson Crusoe economy, an analogous situation would be an islander who supposes that burning wood in a fire does not entail giving up the use of that wood for shelter. Reading the table's columns from left to right reveals an interesting economic phenomenon. The production possibilities curve is farthest from the origin under the Empty Reservoir baseline, contracts toward the origin under the Partly Full baseline, and rests at the origin under the Turbine Bypass baseline. It then inverts into the third quadrant under the Full Reservoir baseline, where the provided quantity of reservoir-based recreation and foregone quantity of recoverable river-based recreation are both nonpositive.<sup>26</sup>

The second economic view involves the distinction between short-run and long-run costs — language this article has generally avoided because of its likely association with the measurement unit of dollars. Short-run thinking means that at least one foregone opportunity continues regardless of the generated electricity quantity. That is, continued power generation entails some level of fixed economic cost, where economic cost refers to giving up the next-best alternative use opportunity of a productive resource. All economic costs are variable under long-run thinking, however, which indicates that all resources currently devoted to continued power generation can instead be directed to their next-best alternative use under license denial. To the extent that continued power generation relies on continued water storage and continued water storage in turn imposes foregone opportunities, this suggests the end of all storage-imposed

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26. The article generally omits the use of prices in order to focus on the quantity measurements familiar to those who are not economists. This removes a dimension from the relicensing problem, which permits the concurrent examination of multiple production possibility settings under different license denial storage regimes. In turn, this permits the systematic measurement error and confounding conclusions.

foregone opportunities under license denial. In other words, long-run economic thinking suggests the use of the Empty Reservoir baseline when relicensing hydroelectric facilities.

This observation is important for both economic and legal reasons. Economically, it suggests the source of the apparent debate between Loomis et al., who asserted that the failure to use non-market valuation methods "often results in an implicit value of zero being placed on ecosystem services,"<sup>27</sup> and Stephenson and Shabman, who noted the lack of strong evidence for detrimental outcomes in hydroelectric relicensing.<sup>28</sup> The Turbine Bypass column of Table 1 shows that continued power generation imposes rather little in the way of foregone opportunities. This is a legitimate short-run view of hydroelectricity's economic cost because it completely separates continued water storage effects from continued power generation effects, which means that the opportunity costs of continued water storage continue regardless of the generated electricity quantity. However, the Empty Reservoir baseline completely combines continued water storage effects with continued power generation effects so that all storage-imposed foregone opportunities are expected to end upon license denial. In that case, long-run thinking indicates that the FERC document, by omitting mention of foregone yet recoverable river-based recreation, sensibly omits a valuable recreation quantity by regarding it as zero.<sup>29</sup> Such an approach mirrors the analytical approach of this article. The alternative explanation is that the FERC document regards this recreational type as valueless, which is the position expressed by Loomis et al.<sup>30</sup> Legally, Congress may have intended that rivers be restored to a freely flowing state when license denial ends electricity production, in the same basic way that Wyoming prairies are restored after coal is mined, by viewing hydroelectricity production and its water storage as temporary river uses.

This section, then, has used economic and statistical thinking to examine a largely stylized set of measurements recorded in a FERC environmental impact analysis. The measurements were recorded and examined in quantity units familiar to scientists who are not economists, and the analysis set aside the price notion of relative value that economic analyses typically employ. As a result, the data set emerges as one plagued

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27. Loomis et al., *supra* note 5, at 104 (although there the assertion was not made in the context of hydroelectricity). Also recall *supra* note 19, which observes that regarding foregone yet recoverable river uses as valueless would justify their absence in the FERC document.

28. Stephenson & Shabman, *supra* note 4, at 502.

29. The recoverable quantity of river-based recreation exceeds zero under long-run thinking. If FERC regards this quantity as zero, then the agency's data record is incorrect. Proceeding from that incorrect data record, however, the omission itself is sensible.

30. See *supra* note 19, which dismissed other explanations for the FERC omission as either untenable or indicative of an overstated figure for reservoir-based recreation.

by systematic measurement error because no single license denial water storage regime contains correct values for all recorded measurements. The approach suggests an interdisciplinary, yet economically based, procedure for assessing whether the experimental design and data use in relicensing rest on a single baseline common to all scientific disciplines, which is developed in the next section. The process explicitly and directly relies on measurements recorded by other scientists in their units of choice and refrains from discounting and dollar-denominated measurements.<sup>31</sup> At the same time, it permits the expression of an economic view for a basic relicensing problem.

### III. AN EXPERIMENTAL DESIGN ASSESSMENT METHOD

Economically, firms are presumed to maximize profits, which are defined as the difference between revenues and costs. Since firms participate in hydroelectric relicensing, perhaps reluctantly, relicensing is an opportunity to pursue profit maximization. To the extent that beneficial effects of continued power generation contribute to revenues, that mitigation of harmful effects contributes to costs, or that provision of beneficial effects can be used to offset mitigation of harmful effects, profit maximization provides an incentive to seek generously measured beneficial effects and restrictively measured harmful effects. That is, firms have an incentive to use, say, the Empty Reservoir baseline or  $0_{\text{Empty}}$  measurement standard when recording beneficial effects of continued power generation. Such measurements combine reservoir effects with power generation effects under the single heading of power generation effects. At the same time, firms have an incentive to use, say, the Turbine Bypass baseline or  $0_{\text{Current}}$  measurement standard when recording harmful effects of continued power generation. Such measurements separate or remove reservoir effects from power generation effects and thereby produce smaller power generation effect measurements; these can economically be termed net measurements because continued water storage effects are netted against continued power generation effects. Large beneficial effect measurements improve the chance of license renewal, and small harmful effect measurements avoid potential mitigation costs or mandated operational changes.

This section presents a procedure for assessing how successful power companies are in achieving that goal. The economic rationale is clear:

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31. Recovery of many river attributes, if possible, is likely to take many years, and economists would typically address this with a discount rate that gives less weight to data values at more distant times. The discussion is static in nature and abstracts from discount rates, in part because other scientists may have concerns about discount rate use. See, e.g., Russell Lande et al., *Optimal Harvesting, Economic Discounting and Extinction Risk in Fluctuating Populations*, 372 NATURE 88, 89 (1994).

success yields a subsidy, and greater success by one firm relative to another creates a comparative advantage to the extent that the electricity market is or becomes competitive. The more general scientific rationale behind this assessment is to avoid confounding effects and systematic measurement error by implementing careful experimental design and data treatments. Power company success in using different measurement standards for beneficial and harmful effects indicates a biased or otherwise flawed experimental design, the lack of appropriate data treatments, or both. The legal rationale is the principle of equal consideration required in the FERC relicensing process: subsidies derived from a biased or flawed experiment that favors power companies by using different measurement standards for beneficial and harmful effects may violate the law.

Table 2 illustrates the procedure's presentation structure. The table essentially parallels Table 1, with columns that identify the four operating effect baselines or measurement standards discussed in the text, namely the different license denial water storage regimes; rows that identify various goods, services, or amenities; and coded data values. The table converts the Table 1 observations to a coded numerical form but is otherwise merely suggestive. For example, not all rows are filled. In particular, the table suggests that the Table 1 analysis can be generalized by considering the complete list of operating effects from an existing hydroelectric project rather than the small data set examined for Table 1. The text then discusses certain coding possibilities without presenting an exhaustive analysis. In addition, the text neither presumes nor examines statistical properties because the coding serves an identification purpose.

In greater detail, the leftmost column identifies power generation and certain particular goods, services, or amenities that may be provided or harmed by continued power generation, along with measurement units for particular quantities. The rightmost column provides space for identifying subsidiary relationships or other information needed for particular measurements.<sup>32</sup> The effect rows are subdivided into three categories: power production itself, external beneficial effects, and external harmful effects. These categories apply to each of the license denial storage regimes included in the middle column; the effect grouping reflects the fact that beneficial and harmful effects themselves cannot be characterized without some water storage determination.<sup>33</sup> As structured, the table

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32. Compare *supra* note 22, which observed that fish may not encounter a passage obstacle whose length equals that of a dam and filled reservoir site when their passage timing coincides with an unfilled reservoir.

33. Using the Full Reservoir baseline or  $O_{Full}$  measurement standard, for example, indicates a full reservoir license denial storage regime. If annual reservoir inflows can keep a reservoir filled and continued power production does not, then reservoir-based recreation is harmed by continued power generation and river-based recreational opportunities are

applies to one year and provides an economic view in one market where positive and negative externalities exist. Greater time detail might be achieved by subdividing within and below the different measurement standards with additional columns.<sup>34</sup>

Data codes are based on the arguments presented in the text. In ascending order, the codes begin with -1. This code indicates that a measurement should not be positive under a particular measurement standard. The next code is 0, which indicates that an effect measurement should be zero (direct) or nearly zero (indirect) under a particular measurement standard.<sup>35</sup> A coded value of 1 indicates that an effect under a particular measurement standard should be smaller than the recorded measurement, so a recorded measurement is overstated under that standard. A coded value of 2 indicates a correctly recorded measurement under a particular measurement standard. Finally, a coded value of 3 indicates that an effect under a particular measurement standard should be larger than the recorded measurement, so a recorded measurement is understated when using that particular measurement standard. Aside from missing or omitted information, these five codes exhaust the systematic measurement error possibilities: a recorded measurement considered under a particular measurement standard is either correct (2), overstated (1), understated (3), not necessary because the direct effect is zero (0), or has been measured in the wrong direction (-1).

Thus, the codes abstract from random measurement errors to focus instead on systematic measurement errors. The table and codes provide data to examine the structure of a relicensing problem, although two cautionary notes should be considered. First, the codes are merely ordinal in nature. In particular, the -1 code relative to the 2 code may suggest that the magnitude of a directional error will be smaller than a correct recorded measurement, which may be incorrect. Normalizing the stored water quantity to the [0,1] interval on the  $x$ -axis, with a related quantity

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provided by continued power generation. The beneficial and harmful effect characterizations can be reversed by the choice of measurement standard, so the standard must be specified in order to know what is beneficial and what is harmful.

34. For example, the table's single-year structure might be subdivided to focus on seasonal effects or years might be added to address effects over longer periods. The latter approach would raise the topic of discounting. As presented, the table provides a snapshot representing a static analysis.

35. Recall that economic theory did not permit a precise statement about reservoir-based recreation provided by continued power generation under the  $0_{\text{Current}}$  measurement standard due to the possibility of indirect price effects, and that the discussion then abstracted from this difficulty for all examined standards. The coding could reflect the lack of certainty by adding a  $\pm$  symbol to indicate that an effect of uncertain direction exists. Certainty in direction alone could be similarly addressed with plus for results near zero but positive and minus for results near zero but negative.



normalized on the  $y$ -axis, indicates the nature of the required relationship under  $O_{\text{Empty}}$ . The suggestion will be valid when the line denoting the relationship sits above the line  $y = 1/2$ , because  $O_{\text{Empty}}$  measurements proceed upward from the horizontal axis and  $O_{\text{Full}}$  measurements proceed downward from the top of the unit square.

Second, the coding descriptions contain certain ambiguities because they are not mutually exclusive. For example, suppose a recorded measurement is overstated because it should actually be zero, which arises in the reservoir-based recreation row and  $O_{\text{Current}}$  (that is, Turbine Bypass) column. Or suppose a measurement is correctly recorded as zero (perhaps by the measurement's omission), which arises in the river-based recreation row of the same column. Should the coding in the first instance be 1, to focus on the overstatement, or 0, to focus on what the measurement should have been? Should the coding in the second instance be 2, to focus on a correct data record, or 0, to focus on what the data record should have been? Similarly, a recorded positive value for a measurement that should not be positive may be regarded as an overstatement. The text and Table 2 resolve these ambiguities by coding errors with what should have been and by coding correctness with what is. When the data record is accurate, a 2 code is assigned; when the data record is inaccurate, the selected code conveys the nature of an accurate measurement.

Data codes thus rest directly on measurements recorded by scientists in disciplines other than economics in units of their choice. The codes ask scientists to closely examine recorded measurements using the approach of the previous section: What would this measurement be like if license denial ends hydroelectricity production and this water storage regime ensues? In other words, how would the recorded measurement of a good, service, or amenity be regarded under each measurement standard? Scientists from many disciplines can then combine and summarize their observations for policy makers. Hence the procedure is inherently interdisciplinary—it relies on the expertise of both economists and other scientists—and it generates data useful for analyzing policy and policy enforcement.

The contribution of economists is likely to be one or both of two types. As discussed below, the procedure does not accept the absence of a recorded effect at face value. Properly accounting for the external social costs of continuing to generate power at an existing hydroelectric project first requires recognition of foregone opportunities. These are the costs that power companies may attempt to deny or understate and this text primarily considers. Alternatively, economists may also be of service in pointing out attempts to overstate or unnecessarily measure benefits. Other than these contributions, scientists in other disciplines are presumed to record quantities according to their own disciplinary judgments. For example, other scientists may have selected a measurement procedure that was both

less expensive and less precise than an available alternative. The table and coding procedure accept this and similar choices at face value.<sup>36</sup> In addition, the data recorded by other scientists are presumed to be correct under some measurement standard and to be made with certainty, absent some other source of systematic error.<sup>37</sup> The focus is on recording all measurements indicated by a particular standard and on having all scientists proceed under the same standard.

Finally, the table has two remaining presumptions. First, it supposes that there exists exactly one value for the quantity of any good, service, or amenity that is provided or harmed in one year, although that value may have been omitted or may be incorrectly recorded when considered under a particular measurement standard. Second, the table presumes that measurements used for coding purposes are taken from documents at a well-defined stage of the relicensing process — perhaps from an initial license application or FERC environmental analysis, with the possible exception of missing information. The table also has a notable drawback: itemizing effects separately largely ignores important relationships between measured quantities in order to concentrate on the relationship with the water storage regime. This seems acceptable because the approach is designed as a tool for evaluating the structure of a relicensing problem and because a number of relationships will at least be enumerated or suggested.<sup>38</sup>

### Applying the Model

In principle, all scientists and policy makers involved in relicensing should consider the same alternative scenario in their decision making,

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36. The codes can at least partially be viewed using thinking like “Suppose an amount of X is worth a dollar.” In effect, the table regards the measurements of other scientists as valuable simply because the scientists decided to record them or not do so. The procedure then assigns the 2 code when the data record accurately reflects the loss of a beneficial effect or avoidance of a harmful effect under a particular license denial storage regime. Some other code appears when the data record is inaccurate.

37. Recall the way in which Table 1 was developed. Each stylized measurement from the FERC document was initially regarded as correct and then was seen to be correct under a particular license denial storage regime. The systematic errors did not emerge until the set of measurements was considered collectively.

38. For example, these relationships might consider reservoir-based recreational opportunities and dry land recovery opportunities. As previously noted, the article considers the information that feeds into tradeoff analyses rather than considering the tradeoffs themselves. Itemizing beneficial and harmful effects separately, however, suggests possibilities for strategic behavior in relicensing. Interest groups centered around reservoir-based benefits rather naturally oppose groups centered around opportunities foregone by storing water.

which means that the baseline for all operating effect measurements should be the same license denial storage regime no matter which scientific discipline measures particular effects. A relicensing data set that strictly relies on one common measurement standard will therefore reveal two specific characteristics: a column of 2 codes under a single license denial storage regime along with the absence of omitted rows. Departures from that result invite investigation, which is what occurs with this stylized set of FERC data.

The stylized data set derived from the FERC document records annual electricity production and annual reservoir visits at an existing hydroelectric project. Also recorded are linear river miles of obstructed fish passage throughout the filled reservoir site. Assuming each measurement is correct, the first two accurately record license denial losses and the third accurately records a license denial gain, when considered under  $0_{\text{Empty}}$  and presuming no effect from a license denial change in the price of electricity. Similarly, the FERC document also records a foregone yet recoverable acreage of dry-land habitat based on a reservoir at 25 percent of its capacity, which accurately records a license denial gain under  $0_{\text{Low}}$ . Finally, the FERC document does not record a measurement for foregone yet recoverable river-based recreation, which is regarded as the sensible act of not recording a zero measurement and which is both accurate and appropriate under  $0_{\text{Current}}$ . Otherwise, the table suggests its potential broader use by providing a beneficial effect (an avoided air pollutant) not yet discussed in the text and by using the etcetera designation to suggest consideration of other hydroelectricity effects with which readers may be familiar.<sup>39</sup>

Attention first centers on the [2, 1, 0, -1] coding of the reservoir-based recreation and fish passage rows, which are derived by applying the codes to the corresponding written observations from Table 1, with the 0 codes in the  $0_{\text{Current}}$  column. (Recall that the entire column could contain 0 codes. Continued power production leaves recoverable river-based recreation essentially unaffected if license denial means merely bypassing turbines.) These results express the following intuition: continuing to generate power at an existing hydroelectric facility produces substantial

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39. For example, the Colorado River emerges clear and cold from Lake Powell after electricity is generated at Glen Canyon Dam. It does not do so because turbines filter or refrigerate but because the reservoir's slack water and thermal properties permit sediment and colder water to settle. The clarity and temperature effects occur to the extent that the reservoir produces them; the magnitude and direction of ongoing power generation effects depend on the extent to which ending electricity generation will change the reservoir. In particular, trapped sediment at hydroelectric sites may resemble mine tailings, depending on the type and quantity of waste that settles with the mineral matter. A long-run or empty-reservoir perspective therefore suggests that the industry's particular method of storing its energy-producing inventory reflects a hidden waste repository rather than cleanliness.

effects in gross terms when  $0_{\text{Empty}}$  applies, as shown by the leftmost 2 codes, and smaller effects in net terms when continued storage effects are removed from continued power generation effects, as shown by the 0 codes. This occurs whether the effects are beneficial or harmful. Continued power production at this project provides a sizable quantity of recreational reservoir use and obstructs a sizable quantity of recoverable passage miles if the specific license denial alternative is to end water storage, namely, to use the  $0_{\text{Empty}}$  measurement standard. This comports with certain commonly expressed views about both beneficial and harmful effects of hydroelectricity production. Alternatively, the effects of continued hydroelectricity production are essentially benign if the specific license denial alternative is to simply bypass turbines, namely, to use the  $0_{\text{Current}}$  measurement standard. This agrees with other commonly expressed views that hydroelectricity is a clean and low-cost source of power.

Thus, applying the coding to the data analysis in Table 1 reveals the likely source of differing views about the external effects of continuing to operate existing hydroelectric plants: a failure to specify exactly one license denial storage regime as the measurement standard and the resulting use of multiple standards. Once in place, this method of power generation produces little in the way of either positive or negative external effects compared to the turbine bypass option (which leaves everything in place other than spinning turbines). By contrast, continued power generation does noticeably more in both beneficial and harmful terms when compared to the option of emptying the reservoir. The coding also reveals the foundation for a fundamental tenet of economic theory — an alternative must be specified in order to assess tradeoffs because tradeoffs use measurements that also require specifying an alternative. The external effects of continued hydroelectric power generation cannot be correctly understood at their most basic level unless exactly one license denial water-storage regime is specified before any external effect measurements are adopted for use in relicensing decisions.

Next, consider that, if license denial means leaving behind an empty reservoir site, the coding in the dry land habitat row should be [2, 1, 0, 0]. From left to right, this essentially indicates a recoverable acreage under license denial and, thus, an opportunity cost under current generation practices that diminishes when larger license denial storage quantities are considered. All acres inundated by a full reservoir are included under  $0_{\text{Empty}}$ , fewer acres are included under  $0_{\text{Low}}$ , and zero acres are recovered under either  $0_{\text{Current}}$  or  $0_{\text{Full}}$ .

Taken together with the [2, 1, 0, -1] coding of the reservoir-based recreation and obstructed fish passage rows, this coding would indicate that the dry-land measurement was performed using the same baseline as the other two measurements because all three coding results would have a 2 code in the leftmost position. Instead, the actual coding for this stylized

FERC document measurement is [3, 2, 0, 0], as shown in Table 2. In comparison to the [2, 1, 0, -1] coding of the reservoir-based recreation and obstructed fish passage rows, visitor-days of reservoir-based recreation and river miles of obstructed fish passage have been correctly recorded under  $0_{\text{Empty}}$ , while acres of foregone dry-land recovery have not. Rather, acres of foregone dry-land habitat have been correctly recorded under  $0_{\text{Low}}$  and understated under  $0_{\text{Empty}}$ . Some acreage of interest to terrestrial biologists and others has not been included under  $0_{\text{Empty}}$  because a different standard of measurement was apparently used.<sup>40</sup> This error occurs before any economic effort to measure the value of recovery on those acres in dollar terms and before any similar effort to provide tradeoff information relative to other effects like reservoir-based recreation.

This type of error understates a legitimate social cost when using  $0_{\text{Empty}}$  and is therefore a source of subsidized hydroelectric power generation. In controlled experiment terms, suppose that both a beneficial effect and a harmful effect increase with treatment and results are reported only for the higher of two treatment levels. This error type permits beneficial effect reporting relative to the absence of treatment and harmful effect reporting relative to the low treatment level; the error fundamentally misstates the harmful effect measurement relative to the beneficial effect measurement. A pattern of similar measurement problems indicates bias in the experimental design or data treatments used to inform a relicensing decision and to prompt consideration of harmful effect mitigation measures. It then becomes difficult to imagine an equal consideration result emerging from the remainder of a relicensing process.

The remaining measurement from the FERC document concerns foregone yet recoverable river-based recreation. If license denial means leaving behind an empty reservoir site, the coding in this row should be [2, 1, 0, -1], which exactly matches the existing rows for reservoir-based recreation and obstructed fish passage. Briefly, a degraded form of river-based recreation can occur throughout the entire reservoir site length if the measurement proceeds under  $0_{\text{Empty}}$ , as shown by the 2 code, and river-

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40. Caution is needed in reaching the conclusion that a different standard of measurement has actually been used. The discussion omits indirect electricity price effects, which may coincidentally produce a systematic quantity error that precisely mimics the systematic error resulting from use of a different measurement standard. This seems unlikely for any single understated harmful effect and less likely still for all understated harmful effects; the article primarily addresses a pattern of understatement potentially discoverable in a collation of the latter. This qualification therefore emphasizes the potential usefulness of economic analysis in the relicensing problem as well as the potential usefulness of considering multiple measurement standards. An understatement under  $0_{\text{Empty}}$  suggests the use of a different measurement standard when paired with a correct value under a different measurement standard. The absence of an alternative understatement explanation, such as systematic error mimicry, verifies the use of a different measurement standard.

based recreation will be unaffected by license denial under  $0_{\text{Current}}$  as shown by the 0 code. Instead, the actual coding for this stylized FERC document measurement is [3, 3, 2, -1]. The existing data record understates recoverable river-based recreation if license denial means leaving behind an empty reservoir site, as shown by the leftmost 3 code, and instead records a zero value (by omission) that is correct if license denial means bypassing turbines, as shown by the 2 code.

This error indicates that power generation is subsidized due to a complete failure to acknowledge a legitimate social cost, namely the river-based recreational use that is recoverable if license denial means ending water storage and is thus given up by continuing current power generation practices. In controlled experiment terms, the failure excludes a known harmful effect from the experiment's set of measurements, while the known beneficial effect of provided reservoir-based recreation is included. Complete failures like this prevent economists, other scientists, and policy makers from recognizing and considering certain social costs of continued hydroelectric power generation before they can be measured, before tradeoffs regarding other external effects can be addressed, and before electricity reaches consumers at some price. A pattern of similar omissions or missing entries is an indication of bias in the experimental design itself. This also makes it difficult to imagine an equal consideration result emerging from the remainder of a relicensing process.

Other potential coding results, which are suggested rather than provided in Table 2, offer other insights. The equilibrium power quantity will fall if hydroelectric power were replaced with power from a more costly source that results in a higher price. This means that an existing power production measurement overstates the expected electricity quantity under license denial. Prospective license denial then indicates a [1, 1, 1, 1] coding. Similarly, the coding would be [2, 2, 2, 2] if no price change is predicted and [3, 3, 3, 3] if a falling price is indicated. The codes remain constant across the different measurement standards because consumers are presumed to be indifferent about the source of electricity, so electricity use is not related to water storage practices. Measurements of an avoided air pollutant can be included if thermal generation is the replacement considered for hydroelectric generation. The procedure again reveals that knowing a specific alternative is a prerequisite to proper measurement in the relicensing problem – knowing whether or not to include measurements of an avoided air pollutant depends on specifying an alternative source of electricity. If indicated, this coding result would presumably be [2, 2, 2, 2]. Coding in the power quantity row addresses the electricity price response, if any, and the coding recognizes recorded measurements for the avoided pollutant as being correct. The presumption rests on the lack of any substantial relationship between air pollution measurements and water storage practices. Similar results would be expected for other beneficial and

harmful effects that are not related to water storage practices, so that no confounding difficulties arise from this source. Of course, this does not eliminate the possibility of important confounding effects from other sources, which this article does not examine.

No single license denial storage regime contains correct measurements for all effects examined in this stylized data set because correctness would appear as a column of 2 codes under that license denial storage regime. This fact is inconsistent with a scientific process that uniformly assumes a single license denial storage regime when measuring the effects of continued project operations. Both the river-based recreation and dry-land habitat measurements are understated if license denial means ending water storage, as shown by their 3 codes in the  $0_{\text{Empty}}$  column, and are correctly measured under different license denial storage regimes, as shown by the differing column locations of their respective 2 codes. These 3 codes in that column indicate that, if license denial means leaving behind an empty reservoir site, foregone opportunities are being understated. Thus, the harmful effects of continued project operations are greater than those measured in the FERC document, potential mitigation measures for these harmful effects are unlikely to be properly and fully considered, and the weight of evidence supporting license denial is larger than admitted.

Indeed, the coding can reveal in sensible but crude terms either a balance or net view of whether relicensing should be favored under a particular circumstance. Suppose that all beneficial and harmful effects are correctly included and are measured under a single standard, which will yield a complete column of 2 codes. Then suppose that hydroelectric power generation and its external beneficial effects are considered jointly as social goods, that external harmful effects are considered collectively as social harms, that social goods and social harms are equal in number, and that all are equally valued at the margin. If so, replacing hydroelectric generation with electricity from a more costly alternative that has no external benefits of its own shifts the balance from indifference to harm and the net from zero to negative. There would be precisely as many beneficial 2 codes as harmful 2 codes if current practice continues, but for coding power generation with a 1 code to reflect the more costly replacement source and expected higher electricity price. This potential shift indicates that approval of a new license should be favored over denial.

This section has presented a procedure and coding mechanism that economists and other scientists can use to examine the experimental design and data treatments that inform hydroelectric relicensing decisions. The procedure's tabular structure is that of a relicensing problem with positive and negative externalities in the electricity market. This coding example, which used stylized data derived from an actual FERC environmental analysis, considered correct identification and measurement of external effects due to continued hydroelectric power generation at an existing

facility where reservoir-based recreation and a complete fish passage obstruction exist. The example showed the presence of systematic measurement errors no matter what license denial storage regime was considered. It also showed the clear understatement or outright omission of harmful effects, namely effects that suggest or indicate mitigation measures and weigh against a new operating license if the specific license denial alternative is emptying the reservoir. The only beneficial effect examined, which supports a new operating license, was fully and correctly measured under this same license denial alternative. This article now concludes with reflections on the experimental design and policy implications derived from the procedure.

#### IV. CONCLUSIONS AND POLICY IMPLICATIONS

The analysis of hydroelectric relicensing in this article relies on economic, scientific, and legal principles. Economically, power companies have an incentive to use the relicensing process as an opportunity to pursue subsidized power generation. Scientifically, proper measurement requires that a single measurement standard be used for all relicensing measurements along with their interpretations and uses, and it requires that measurements indicated under that standard be rigorously pursued. This ensures that all scientists address their respective aspects of the same experiment, that confounding is avoided or properly addressed, and that indicated measurements are not omitted. Legally, equal consideration of power and non-power values is mandated. The success of power companies in achieving their economic goals conflicts with the achievement of the scientific and legal requirements of relicensing.

From a different perspective, this analysis rests on the mathematical observation that finite, nonzero number-line representations of quantitative relicensing measurements have two endpoints. It also rests on the statistical observation that these endpoints represent the end of power generation via license denial and the continuation of current power generation practices. The measurements thus obtained can be sorted into beneficial and harmful effects, where the former support a new license and the latter support license denial. These are the data values relevant for the simplest relicensing question—do measurements support a renewed license, yes or no? Any operational changes, mitigation measures, or associated tradeoff analyses that may subsequently be considered rest on this foundation.

This article examined a small set of familiar, yet stylized, measurements from a FERC environmental analysis prepared for a project in the western United States at some point in the past several years and kept these measurements in the quantity form directly obtained by scientists who are not economists. It also set aside all notions of relative value that economists would customarily employ, namely prices, which are intratemporal, and



discount rates, which are intertemporal. This approach revealed the presence of systematic measurement errors in the FERC document, which were presented in a written form (Table 1) and a coded numerical form (Table 2). These errors occurred because certain recorded measurements were correct under certain license denial water storage regimes, which were referred to as operating effect baselines or measurement standards, but were incorrect under other regimes. There was no single license denial regime under which all measurements were correct, however, and systematic errors were present regardless of the license denial storage regime considered. The empirical example was narrow in scope and the derived data were limited, although it is reasonable to expect that such familiar measurements will be recorded without systematic error. Also, not all license denial storage regimes were considered; however, the analysis only omitted a varying license denial reservoir level with water storage and release attributes that differ from existing generation practices in ways other than bypassing turbines.

Several additional observations also emerged from this analysis. First, measurement policy in hydroelectric relicensing requires specification of a single license denial water storage regime. The issue of dam removal, either partial or complete, is distinctly secondary because dams can stand without water being stored. A dam removal policy implies zero storage if a license is denied, which corresponds to the article's  $0_{\text{Empty}}$  measurement standard. However, if the plan does not include dam removal, then the measurement standard needs to specify exactly one license denial storage regime lest the policy lack precision and provide inadequate scientific direction.

Second, a policy of zero storage in the event of license denial is defensible as the measurement baseline. The data set's correct measurements under this standard agreed with views that continued hydroelectric generation provides sizable benefits and imposes sizable harm. Furthermore, this standard is a natural (though not the only) scientific alternative. None of the other examined standards provided both broad agreement and an intuitive scientific rationale. Indeed, it may be difficult to imagine a justification for other license denial storage regimes. For example, how would one justify a nationwide measurement policy that beneficial and harmful operating effects of existing hydroelectric plants will be based on presuming that license denial means holding reservoirs at 25 percent of their capacity?

Third, the general public may well misunderstand the problem and therefore use or fail to discern multiple measurement standards for two particular reasons. One is that measurements that are useful for evaluating new projects differ from measurements that are useful for evaluating existing projects. The former consider the potential onset of hydroelectricity production relative to its absence and the latter consider the continuation

of existing hydroelectric production practices relative to ending power production. Thus, constructing a new project may provide 100,000 annual visitor-days of reservoir-based recreation. Yet, if license denial means merely bypassing turbines, then none of these visits are actually at stake in the relicensing process. Therefore, none of these visits should be regarded as relevant effects of continuing to operate an existing hydroelectric plant.

This conclusion relates to the second source of public misunderstanding, namely that the license denial water storage regime simultaneously determines the effects of license denial and the effects of continued operations. The legislative intent behind the equal consideration language may ultimately be the best guide to a social consensus and legal conclusion regarding the applicable license denial storage regime: Congress may have viewed the next-best alternative use of existing hydroelectric sites as freely flowing rivers, which indicates use of the  $O_{\text{Empty}}$  standard for measurement purposes. However, it is difficult to imagine that Congress intended a process with systematic error where the generous  $O_{\text{Empty}}$  standard provides large measurements for beneficial effects of hydroelectric production by including water storage effects and other more restrictive standards reduce harmful effect measurements by partially or fully excluding water storage effects and producing understatements.

In addition, a practical observation about the observed systematic errors is that their presence increases the difficulty of conducting the relicensing process. Suppose, for example, that license denial means ending water storage and that river-based recreation is valuable. If so, continued power production maintains the scarcity of this type of recreation. In turn, this will motivate strong mitigation arguments such as suggestions that substitute opportunities be provided or improved elsewhere because value is positively related to scarcity. On the other hand, continued power production at an existing reservoir site imposes the opportunity cost of foregone yet recoverable river-based recreation when license denial means the end of water storage. With a nonzero quantity involved and other explanations for FERC's omission of this recreation type discarded,<sup>41</sup> what remains is an agency that has regarded river-based recreation as valueless. Just as a potential buyer cannot reach agreement with a potential seller when the buyer's maximum acceptable price is less than the seller's minimum acceptable price, those who correctly perceive power-imposed river scarcity and high relative value at an existing reservoir site will find it difficult or impossible to reach mitigation agreements with an agency that, through systematic measurement error, understates or does not acknowledge either the scarcity or value of river attributes.

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41. See *supra* note 19.

At the extremes, the storage regimes under license denial are an empty reservoir site or a full one, so remaining observations focus on these two cases. If the alternative to continued hydroelectric power generation is a full reservoir, then these particular measurements are scientifically indicated for both beneficial and harmful effects. Departures from this standard can occur by either including unnecessary beneficial effect measurements or using overstated measurements, while harmful effects may be omitted or understated. This suggests a twofold focus for parties interested in relicensing—finding overstated or unnecessary beneficial effect measurements and finding understated or omitted harmful effect measurements. The first of these is accomplished by explicitly netting out reservoir effects, even to the degree that nominally beneficial effects become negative and weigh against a new operating license. Doing so deliberately avoids consideration of zero storage. When combined with the second focus, finding harmful effect measurements that understate or omit social costs, error correction would increase the marginal social cost and decrease the marginal social benefit of continuing to operate particular projects. The equilibrium electricity quantity would fall but the effects on price and consumer surplus would not be known without appropriate data. In particular, this type of error retains reservoir fluctuation practices at more reservoirs than is socially optimal.

If the alternative to continued hydroelectric production is an empty reservoir site, these particular measurements are scientifically indicated for both beneficial and harmful effects. Departures from this standard can occur by either omitting or understating harmful effect measurements, while beneficial effect measurements are likely to be fully and correctly measured. Power companies are unlikely to forego relicensing opportunities that permit them to remind FERC of the beneficial effects to be lost upon license denial. This suggests a singular focus on finding understated or omitted harmful effect measurements, which can be accomplished by explicitly considering zero water storage throughout the relicensing process. Otherwise understated or omitted harmful effect measurements understate the social cost of continued hydroelectric generation. The subsidy retains more reservoir sites with nonzero storage than is socially optimal, and correcting the subsidy would decrease equilibrium electricity consumption, increase the price, and lower consumer surplus.<sup>42</sup>

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42. The discussion has concentrated on the environmental components of the equal consideration clause; the concluding paragraphs now address the energy conservation component of that clause. Subsidies promote greater energy use, so the equal consideration clause can be used to argue that the relicensing process is specifically intended to remove existing hydroelectric subsidies, if any, and forbid the development of new subsidies, whatever their source.

Whatever license denial storage regime is used as the measurement standard that informs relicensing decisions, its enforcement is likely to be difficult. First, multiple measurement standards or a fundamental misunderstanding of the problem may well exist in the general public. Second, if the project analyzed in this article is representative of FERC's analytical methods and thus indicates that the agency tends to base relicensing decisions on inaccurate environmental information, consumer surplus either may or will fall by eliminating systematic measurement error. Third, using the Empty Reservoir baseline is likely to raise the controversial topic of possibly breaching existing dams. Using some other baseline may reveal that a variety of sources routinely and perhaps dramatically overstate the beneficial effects of continued generation at existing hydroelectric projects. Alternatively, these sources may be citing information that is irrelevant because it dates to project construction and cannot be influenced by the relicensing process. Fourth, the broad variety of environmental effects provides multiple systematic error opportunities.

Finally, the results of this analysis are valuable to the economics literature, may help forge a stronger relationship between economics and other sciences, and offer guidance to parties interested in relicensing. First, the results reinforce the need for economists to precisely understand the set of production possibilities as research evolves in this policy arena. Indeed, it may be that language stronger than valuing ecosystem services at zero is warranted: all or some of these values are written off when either omission or bias understates foregone opportunities, which are unknown until a single license denial storage regime is specified. For the zero storage option in particular, much of the environmental damage from continued generation may occur in two rather hidden ways. One is delayed recovery opportunities, which in turn may reduce recovery rates and either reduce or eliminate recovery probabilities, and the other is the retention and eventual exposure of sediment that may hold concentrated contaminants. In addition, the approach may help economists convey the idea that the relicensing problem is a scientific exercise that corresponds precisely to standard textbook descriptions of the discipline. The structural form of an economics problem, which involves balancing and tradeoff considerations called for in potentially allocating scarce resources to continued hydroelectricity generation at existing projects, was unavoidably retained when relative value notions were set aside.

Second, the analogy to controlled experiments may provide other scientists a useful window into the economist's differently structured problem-solving world of different weights and measures that still examines the same experiment. By omitting relative value observations, scientists in other disciplines can focus on their own measurements and perhaps realize a need for price or similar value information. Using this article's codes for balancing and optimization purposes only permits the inherent tradeoffs of

potential operating changes or mitigation measures to be evaluated in terms of, for example, three beneficial effects given up for two harmful effects eliminated. Using quantity information alone permits greater precision, such as trading 500 foregone annual megawatt-hours for an increase of 1,000 annual reservoir visitor-days by limiting reservoir fluctuations, but is unlikely to be accurate because it seeks balance and optimization through barter. The approach uniformly avoids obtainable data about the value that society actually places on these small changes, when economists can provide or draw valid conclusions from at least some of that data with reasonable accuracy and precision.

Finally, this article may suggest reallocations of scarce resources among parties interested in relicensing. If zero storage is not the measurement baseline, then concerns about achieving zero storage when license denial ends electricity generation at existing hydroelectric facilities are not relevant. If zero storage is the measurement baseline, then more data supporting that potential outcome may be gathered by explicitly using that baseline and the matter of achieving zero storage when licenses are denied at marginal projects will reduce to a simpler question of how to do so cheaply.

	Empty Reservoir	Partly Full Reservoir (25% Capacity)	Turbine Bypass	Full Reservoir
Provided reservoir-based recreation (100,000 visitor-days/yr)	CORRECT	Overstated	Overstated (measurement should be zero)	Overstated (measurement cannot be positive)
Foregone yet recoverable river-based recreation (no measurement recorded)	Understated (positive measurement omitted)	Understated (positive measurement omitted)	CORRECT (omission of a zero measurement)	Overstated (measurement cannot be positive, yet omitted)
Foregone yet recoverable dry-land habitat (2,000 acres)	Understated	CORRECT	Overstated (measurement should be zero)	Overstated (measurement should be zero)
Obstructed yet recoverable fish passage (30 river miles)	CORRECT	Overstated	Overstated (measurement should be zero)	Overstated (measurement cannot be positive)
	No Separation	Partial Separation	Complete Separation	

Table 1. Error Status for Stylized Hydroelectric Operating Effects Reported by FERC Under Alternative License Denial Storage Regimes

Good/Service/Amenity	Measurement Standard	Other Needed Information
Electricity (GWh/yr)	0 <sub>Empty</sub> 0 <sub>Low</sub> 0 <sub>Current</sub> 0 <sub>Full</sub>	Market information, Alternative power source
Beneficial Effects		
Recreational reservoir use (days/yr)	2 1 0 -1	Alternative power source
Avoided air pollutant (tons/yr)		
Etc.		
Harmful Effects		
Foregone river recreation (days/yr)	3 3 2 -1	
Foregone dry land recovery (acres)	3 2 0 0	
Obstructed fish passage (river miles)	2 1 0 -1	Passage timing
Etc.		

Codes show that existing datum, relative to a correct value under the particular standard,

- 3 ⇒ should be a larger number; an understatement exists.
- 2 ⇒ is correct (supersedes any alternative "should be" code, per text).
- 1 ⇒ should be a smaller number; an overstatement exists.
- 0 ⇒ should show a zero direct effect.
- 1 ⇒ should not be positive; a directional error exists.

0<sub>Low</sub> coding reflects the stylized 25% capacity figure from the FERC analysis. Codes concern measured effects within the geographic boundary of a full reservoir site at an existing hydroelectric project, under and relative to 0<sub>Empty</sub>.

Table 2. Error Codes for Stylized Hydroelectric Operating Effects from a FERC Environmental Impact Analysis