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Rules and Values in Virtual Optimization of California Hydropower

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ABSTRACT

Optimization models for California's hydropower system are designed to be decision-support tools and aids for climate adaptation decision-making. In practice, they fall short of this goal. One potential explanation is that optimization models are not more successful because they are built on, and depend on, a misrepresentation of law and politics. The legal reality of California's hydropower system is a web of networked jurisdictions of multiple federal and state agencies, with varying levels of coordination, long periods of legally obligated stability with rigid rules, and prone to conflict, but with multiple procedures for conflict resolution. Barriers to climate adaptation from that mix vary according to where a given dam is located. The virtual institutional arrangements represented in optimization models are not a simplification of existing arrangements. Instead, they are a dramatic replacement. That replacement is deliberate and reasoned. As seen in two optimization models supported by the state of California, CALVIN and INFORM, the operation of the optimization function of computer models depends on a virtual system of rules that are centrally controlled, coordinated, nimble, and without the possibility of conflict (let alone conflict resolution). But that smooth virtual system comes with a real cost. Institutional economics suggests that this mismatch between existing formal law and represented law may upend the results of models, since value is determined from institutional context.

INTRODUCTION

Here's the story: California—the sixth largest economy in the world, home to 38 million people, 95 endangered species, and 189,454 miles of river[1]—is

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dependent on a variable and fragile hydrological system to support life, energy, and ways of living. That system is vulnerable to climate change. Because the effects of future climate conditions on water and energy systems will diverge from historical experience, decision-makers and stakeholders are dependent on computer models—which "probabilistically" forecast climatic changes and/or their potential downstream sequelae[2]—to evaluate the practical implications of climate change and devise timely harm-reduction policies. Over the past decade and a half, California administrative agencies have funded research to develop engineering models that could assist decision-making to manage strained resources (electricity and water) under conditions of climate change.[3] But despite promising research

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1. STATE OF CAL. DEP'T OF FISH & WILDLIFE, STATE & FEDERALLY LISTED ENDANGERED & THREATENED ANIMALS IN CALIFORNIA (2017), https://nrm.dfg.ca.gov/FileHandler.ashx?Document ID=109405&inline [https://perma.cc/SK96-5TRY].

2. "Computer models" here includes everything from downscaled climate scenarios to engineering models of physical and natural systems, like hydropower and reservoir systems, which use climate scenarios as an input to the model.

3. *See* CAL. CLIMATE CHANGE CTR., OUR CHANGING CLIMATE —ASSESSING THE RISKS TO CALIFORNIA (2006), http://meteora.ucsd.edu/cap/pdffiles/CA_climate_Scenarios.pdf [https://perma.cc/ V9R2-B4AD]; *see also* CAL. CLIMATE CHANGE, SECOND CALIFORNIA CLIMATE CHANGE ASSESSMENT (2010), http://climatechange.ca.gov/climate_action_team/reports/second_assessment.html [https://perma .cc/ALH9-962R] (individual "final reports" available); CAL. CLIMATE CHANGE, OUR CHANGING CLIMATE 2012 VULNERABILITY & ADAPTATION TO THE INCREASING RISKS FROM CLIMATE CHANGE IN CALIFORNIA (2012), http://climatechange.ca.gov/climate_action_team/reports/third_assessment/ index.html [https://perma.cc/325F-YH47]. *See Research and Tool Development*, CAL. NAT. RESOURCES AGENCY, http://resources.ca.gov/climate/safeguardinZg/research/ [https://perma.cc/9BLP-6GTY] (providing information on research portfolios being developed for California's Fourth Climate Assessment); *see also California Climate Change Assessments*, CAL. CLIMATE CHANGE, http://climatechange.ca.gov/climate_action_team/reports/climate_assessments.html [https://perma.cc/ 5CDN-6ZF4] (providing general information on the California Climate Assessments).

For reasons described in discussion *infra* Part III.A.1, the California Energy Commission had been the primary state funder of climate related research until around 2010. Reports discussing the planned funding of climate related research and outcomes of that research include: CAL. ENERGY COMM'N, ELECTRIC PROGRAM INVESTMENT CHARGE 2016 ANNUAL REPORT (2017), http://www.energy .ca.gov/2017publications/CEC-500-2017-015/CEC-500-2017-015.pdf [https://perma.cc/3SFF-ER6Y]; CAL. ENERGY COMM'N, NATURAL GAS RESEARCH AND DEVELOPMENT PROGRAM (2016), http://www. energy.ca.gov/2016publications/CEC-500-2016-063/CEC-500-2016-063.pdf [https://perma.cc/UBV8- N8J7]; CAL. ENERGY COMM'N, ELECTRIC PROGRAM INVESTMENT CHARGE 2015 ANNUAL REPORT, (2016) http://www.energy.ca.gov/2016publications/CEC-500-2016-014/CEC-500-2016-014-CMF.pdf [https://perma.cc/G2JJ-L4R8]; CAL. ENERGY COMM'N, PUBLIC INTEREST ENERGY RESEARCH 2015 ANNUAL REPORT (2016) http://www.energy.ca.gov/2016publications/CEC-500-2016-032/CEC-500- 2016-032-CMF.pdf [https://perma.cc/3EHY-LN2Z]; CAL. ENERGY COMM'N, PUBLIC INTEREST ENERGY RESEARCH 2014 ANNUAL REPORT 73 (2015), http://www.energy.ca.gov/2015publications/CEC-500- 2015-009/CEC-500-2015-009-CMF.pdf [https://perma.cc/CEZ2-S3CA] (topics within the climate energy research area comprising $1.8 million of PIER funding and $165,000 from match funding, 23% of which went to hydropower modelling); CAL. ENERGY COMM'N, PUBLIC INTEREST ENERGY RESEARCH 2012 ANNUAL REPORT (2013), http://www.energy.ca.gov/2013publications/CEC-500-2013- 013/CEC-500-2013-013-CMF.pdf [https://perma.cc/K3LK-JXKC]; CAL. ENERGY COMM'N, PUBLIC INTEREST ENERGY RESEARCH PROGRAM 2010 ANNUAL REPORT (2011), http://www.energy.ca.gov/2011 publications/CEC-500-2011-031/CEC-500-2011-031-CMF.PDF [https://perma.cc/8LT7-NLQQ]; CAL. ENERGY COMM'N, PUBLIC INTEREST ENERGY RESEARCH: A DECADE OF ADVANCING CALIFORNIA results, almost none of these decision-support tools—nor their policy recommendations—have actually been adopted for use by decision-makers. I suggest that a potential reason for poor adoption rests in the model design itself, especially for optimization models of hydropower systems in legally complex landscapes.

Optimization models are designed to weigh costs and benefits of multiple choices to produce a "least-cost" option, based on chosen criteria.[4] These models largely ignore underlying substantive and procedural law and politics, as well as values inherent in, and produced by, both.

The mismatch between the legal and political reality on the ground and how it is represented in optimization models is not an accident. It is deliberate and reasoned. To facilitate the optimization function, models of hydropower systems assume a uniform, centralized, coordinated system with decipherable values.[5]

But what we have is a multi-jurisdiction and multi-objective legal system on the ground, where values can conflict and processes for institutional and operational change vary, and where no set of institutional arrangements is uniform across all river basins. Optimization models swap this "messy" legal and political reality for "cleaner" hypothetical institutional arrangements to determine the value of alternative allocation scenarios.

Institutional economics offers a critique of this kind of replacement. Applied to optimization models of hydropower in California, institutional economics suggests that the method of weighting options in optimization models may be misrepresenting social and economic values when choosing between multiple objectives of reservoir management. In other words, the assumptions made in optimization models have the potential to render their results suspect to decision-makers, because results are removed from the political and legal reality that hydropower managers and policy makers work in. A prescription for the disconnect follows from the institutionalist critique: include legal context in models.

My purpose here is not to reject these tools. I argue, along with many other practitioners, that we are increasingly dependent on models for climate planning and adaptation. What I hope to demonstrate in this article is that these

TECHNOLOGY (2009), http://www.energy.ca.gov/2009publications/CEC-180-2009-004/CEC-180-2009-004.PDF [https://perma.cc/HGS5-XVMG]; CAL. ENERGY COMM'N, PIER 2003 ANNUAL REPORT (2004), http://www.energy.ca.gov/reports/2004-04-01_500-04-010.PDF [https://perma.cc/ATG8-Y3KZ]; 6 CAL. ENERGY COMM'N, 2004 ANNUAL REVIEW OF THE PIER PROGRAM: ENERGY-RELATED ENVIRONMENTAL RESEARCH PROJECT SUMMARIES (2005), http://www.energy.ca.gov/2005publications/CEC-500-2005-055/CEC-500-2005-055-V6.PDF [https://perma.cc/G6B5-KC4H].

Cf. Sacramento Water Allocation Model (SacWam), developed by the Stockholm Environmental Institute and financed by the State Water Resources Control Board. This model also took over a decade to develop and introduce to the public. *See San Francisco Bay/Sacramento-San Joaquin Delta Estuary (Bay-Delta) Program*, CAL. ENVTL. PROTECTION AGENCY, http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/sacwam/ [https://perma.cc/XU4X-DQAZ]; *see also Sacramento Water Allocation Model (SacWam) Independent Peer Review Workshop*, DELTA STEWARDSHIP COUNCIL, http://deltacouncil.ca.gov/events/science-program-workshop/sacramento-water-allocation-model-sacwam-independent-peer-review [https://perma.cc/HC3H-MQ77].

4. For a description of "optimization models" for non-experts, see 1 KATTA G. MURTY, OPTIMIZATION MODELS FOR DECISION-MAKING: JUNIOR LEVEL 9–13 (2003), http://www-personal.umich.edu/~murty/books/opti_model/ [https://perma.cc/4TMY-TL8E].

5. *See* discussion *infra* Part III.

tools have flaws, which may prevent successful integration into planning, if not addressed.

Throughout this article, I rely on two optimization models as examples—CALVIN (CALifornia Value Integration Network) and INFORM (Integrated Forecast-Management System)—to explain the ways in which legal context is ignored, replaced, and in some cases included. These models were chosen because over the past decade their research and development has been funded in large part by the state of California as potential decision-support tools for adapting California's water and energy systems to climate change. And they have been highlighted in prior California Climate Assessments.[6]

A main theme of this article is the ways in which "value" is represented in models. "Value" is a notoriously tricky concept to pin down, and deserves some upfront explanation to avoid confusion. There are at least three different faces of value; and value shows each in different contexts. In sociology, ethics, and common speech, value can convey something like "dearly held beliefs" or guiding principles.[7] In economics, there are other faces. "Use value" is one of these; roughly speaking, it is the relative importance of a thing in use[8]—i.e., the "use value" of water tends to be high, while the use value of diamonds is low. Value can also indicate "exchange value," otherwise known as price[9]—high for diamonds, low for water. Exchange value and use value depend on an individual or group's guiding principles (ethical, ideological, or social values). Optimization models depend on calculating exchange value, whereas law is largely concerned with reflecting the ethics face of value.[10]

For purposes of this article, I intend "value" to be read in an inclusive way. For example, if hydroelectricity is curtailed in order to protect aquatic habitat, that curtailment can be read as an expression of guiding principles—e.g., environmental protection, among others. Likewise, if hydroelectric generation is curtailed and water is redirected to, say, irrigation because it is not profitable to

6. Christina R Connel-Buck et al., *Adapting Climate's Water System to Warm vs. Dry Climates*, *in* SECOND CALIFORNIA CLIMATE SCENARIOS ASSESSMENT 133–39 (Daniel R. Cayan et al. eds., 2013); *see also* CAL. CLIMATE CHANGE CTR., OUR CHANGING CLIMATE 2012: VULNERABILITY & ADAPATION TO THE INCREASING RISKS FROM CLIMATE CHANGE IN CALIFORNIA 6 (2012), http://www.energy.ca.gov/2012publications/CEC-500-2012-007/CEC-500-2012-007.pdf [https://perma.cc/3ZET-59EP].

7. Jürgen Habermas defines value as "intersubjectively shared preferences" distinct from norms, "[s]hared values express the preferability of goods that, in specific collectivities, are considered worth striving for and can be acquired or realized through goal-directed action." JÜRGEN HABERMAS, BETWEEN FACTS AND NORMS 255 (William Rehg trans., 1996). For discussions of non-economic values of water, see generally Helen Ingram, *Water as a Multi-dimensional Value: Implications for Participation and Transparency*, 6 INT'L. ENVTL. AGREEMENTS: POL., L. & ECON. 429, 429–33 (2006).

8. JOHN R. COMMONS, LEGAL FOUNDATIONS OF CAPITALISM 11 (1924).

9. William M. Hanemann, *The Economic Conception of Water*, *in* WATER CRISIS: MYTH OR REALITY? 62 (Peter P. Rogers et al. eds., 2006) ("[E]conomic value is different than price. Price does not in general measure economic value, and items with no market price can still have a positive economic value.").

10. "[M]odern law lives off a solidarity concentrated in the value orientations of citizens and ultimately issuing from communicative action and deliberation. . . . [T]he jointly exercised communicative freedom of citizens can assume a form that is mediated in a variety of ways by legal institutions and procedures, but it cannot be completely replaced by coercive law." HABERMAS, *supra* note 7, at 33.

produce electricity at a given time, that is another expression of value. What I argue in this article is that because the larger context of value is missing, modelers of hydropower systems incorrectly assign weights to variables to indicate their relative importance in optimization models.

This article begins with a very brief description of the institutional economic framework that I use to examine optimization models. With that background, the article turns to some key components: what hydropower governance in California looks like (Part II), how the state has invested and encouraged the development of optimization models to support hydropower governance (Part III), and how those models rely on replacements (rather than simplifications) of institutional arrangements in order to perform (Part IV). Part V applies lessons from institutional economics to optimization models. I conclude with suggestions for research to facilitate a path forward for better integration between the two opposing worldviews that may lead to acceptable and implementable results from models aimed at facilitating climate adaptation.

I. BACKGROUND ON INSTITUTIONAL ECONOMICS

The problem of how hydropower systems are represented in optimization models is closely analogous to the problems with the application of neoclassical economics to explain or solve conflicts where multiple (non-price) values are at issue. Institutional economics lends a critical outlook to the values considered and projected by the neoclassical approach; it can therefore be applied to decision-support tools like optimization models of hydropower systems.

Institutional arrangements are essential for an accurate understanding of resource allocation and conflicts.[11] These arrangements are "working rules for going concerns";[12] in other words, the formal and informal rules, created through collective action, which form the structure for defining sets of possible options.[13] Sources of formal rules are courts, legislatures, and administrative agencies.[14]

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11. *See* Daniel W. Bromley, *Land and Water Problems: An Institutional Perspective*, 64 AM. J. AGRIC. ECON. 834 (1982) [hereinafter Bromley, *Land and Water Problems*]; Daniel W. Bromley, *Resources and Economic Development: An Institutionalist Perspective*, 19 J. ECON. ISSUES 779, 780 (1985) [hereinafter Bromley, *Resources and Economic Development*] (citing JOHN R. COMMONS, LEGAL FOUNDATIONS OF CAPITALISM 780 (1924)); Philip R. Wandschneider, *Neoclassical and Institutionalist Explanations of Changes in Northwest Water Institutions*, 20 J. OF ECON. ISSUES 87 (1986); Federico Aguilera-Klink & Juan Sanchez-García, *Water Markets in Tenerife: The Conflict Between Instrumental and Ceremonial Functions of the Institutions*, 3 INT'L J. OF WATER 166 (2005); Carl J. Bauer, *Bringing Water Markets Down to Earth: The Political Economy of Water Rights in Chile, 1976-95*, 25 WORLD DEV. 639 (1997) [hereinafter Bauer, *Bringing Water Markets Down to Earth*]; Carl J. Bauer, *Slippery Property Rights: Multiple Water Uses and the Neoliberal Model in Chile, 1981-1995*, 38 NAT. RESOURCES J. 109, 109–155 (1998) [hereinafter Bauer, *Slippery Property Rights*]; CARL J. BAUER, SIREN SONG: CHILEAN WATER LAW AS A MODEL FOR INTERNATIONAL REFORM (2004) [hereinafter BAUER, SIREN SONG]; Carl J. Bauer, *Dams and Markets: Rivers and Electric Power in Chile*, 49 NAT. RESOURCES J. 583 (2009) [hereinafter Bauer, *Dams and Markets*].

12. *See* Bromley, *Resources and Economic Development*, *supra* note 11, at 781–82 (citing JOHN R. COMMONS, INSTITUTIONAL ECONOMICS (1961)).

13. Bromley, *Resources and Economic Development*, *supra* note 11, at 783. *See generally* JOHN R. COMMONS, LEGAL FOUNDATIONS OF CAPITALISM 11 (1924). Other similar definitions are offered by institutional economist Ciriacy-Wantrup: a "social decision system that provides decision rules for adjusting and accommodating, over time, *conflicting* demands . . . from different interest groups in a

Institutions cannot be divorced from history.[15] Law does not just happen. It comes from processes of conflict, deliberation, and resolution. These processes build on past experience and are historical by nature.[16] Wandschneider, in his 1986 study of changes to water rights in the Pacific Northwest, found that social goals, rather than price or scarcity, defined options to change or maintain the rights of fisheries. Existing power relations constituted an initial distribution that conditioned what outcomes were possible. He noted the process for changing water rights was dynamic and full of conflict. Bauer's studies of Chilean water rights likewise emphasize the importance of the specific history leading up to Chile's

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society." *See* S.V. Ciriacy-Wantrup, *Natural Resources in Economic Growth: the Role of Institutions and Policies*, 51 AM. J. AGRIC. ECON. 1314, 1319 (1969) (alteration in original); *see also* Aguilera-Klink & Sanchez-Garcia, *supra* note 11, at 169 (using a similar definition); Bromley, *Land and Water Problems*, *supra* note 11, at 839 ("Institutions are collective conventions and rules that establish acceptable standards of individual and group behavior."); Wandschneider, *supra* note 11, at 93 ("Institutions define the opportunity set within which choice is made, but individual choice, aggregated into collective action, creates the institutional structure.").

14. More specifically, referencing the writings of Commons, Bromley says that capitalism depends on courts and legislatures to create value, while socialism depends on administrative rules for the same. *See* Bromley, *Resources and Economic Development*, *supra* note 11, at 782. Commons' writing though predated the expansion of administrative agencies and regulation in the United States that define operational rules for natural resources.

15. *See, e.g.,* NICHOLAS MERCURO & STEVEN G. MEDEMA, ECONOMICS AND THE LAW: FROM POSNER TO POST-MODERNISM AND BEYOND 112 (2d ed., 2006). This insight is not unique to institutional economics. Within law, the long branch of scholarship stemming from legal realists and American Pragmatism has described law as a project of history. *See* WOUTER DE BEEN, LEGAL REALISM REGAINED: SAVING REALISM FROM CRITICAL ACCLAIM 31–74 (2008) (discussing the relationship between legal realism and legal history and the differences between critical approaches and realist approaches to history); *see also* Louis Brandeis, *The Living Law*, 10 ILL. L REV. 467 (1916) ("[N]o law, written or unwritten, can be understood without a full knowledge of the facts out of which it arises, and to which it is to be applied.").

Sociologists, historians, and political economists, among others, have noted the same. *See* Bryan Randolph Bruns & Ruth Meinzen-Dick, *Frameworks for Water Rights: An Overview of Institutional Options*, *in* WATER RIGHTS REFORM: LESSONS FOR INSTITUTIONAL DESIGN 16 (2005) ("Many new moves to 'establish' water rights act as if there was a blank slate, in which the state holds all water rights and can unilaterally allocate those rights as it wishes. But in almost all cases where water has been in use, existing institutions constitute a system of implicit water rights, based on the ways water is currently being withdrawn, and steps taken or not taken to control withdrawals, particularly during periods of shortage."); RICHARD WHITE, THE ORGANIC MACHINE: THE REMAKING OF THE COLUMBIA RIVER (1995) (connecting environmental history to human history and development of law and bureaucracy on the Columbia River); Karen Bakker, *From State to Market? Water* Mercantilización *in Spain*, 34 ENV'T. & PLAN. 767 (2002) (putting Spanish *mercantilización* of water into political economic context, Bakker suggests that commercialization and privatization of water (*mercantilization*) in Spain was a response to Spanish history, and both politically and financially expedient, as the old hydraulic regime was politically contentious post-Franco).

16. *See, e.g,* Wandschneider, *supra* note 11, at 93 ("Institutional change is cumulative in that feasible alternatives reflect current rules, knowledge, technology, capital stocks and preferences (especially of the powerful), which in turn are all the outcome of previous states and so on. The historical process is not reversible.")

1980 Constitution in setting up the rules for Chile's water market system,[17] and its associated problems with conflict resolution and equity.[18]

At any point within the stream of evolving law, institutional arrangements determine value.[19] How does the relationship between law and value work? Law determines the initial distribution of allocations, or the starting positions for bargaining and exchange, thereby giving certain parties the power to influence the process and outcomes of defining values of the goods or rights involved in the transaction.[20] Another way that law determines value is through rules for exchange. Law determines who can participate in transactions, under what conditions, and with what recourse in case of conflict. These parameters influence how easy it is engage in transactions and the strength of property rights. These types of parameters can be substantive duties—e.g., prohibitions on "take" of endangered species, or the maximum acceptable reservoir level for flood control—as well as procedural requirements, for example, the rules defining the appeals process for re-licensing hydropower dams.

II. LAW AND GEOGRAPHY OF HYDRPOWER IN CALIFORNIA

Before going into greater detail on how value and law are represented in these hydropower system optimization models, it is important to understand some of the institutions that govern the systems represented in them. The legal reality of California's water and energy systems is a web of networked jurisdictions of multiple federal and state agencies, with varying levels of coordination, long periods of legally obligated stability with rigid rules, and prone to conflict, but with multiple procedures for conflict resolution. Each thread of the web has its own history—reflecting changing values and priorities, as well as changes to the political power of different groups. All threads influence one another at points of intersection. Hydropower dams are one of these points.

A. Hydropower Law in California Is Heterogeneous yet Patterned

There is a noticeable split between federal and state law in the mountains of the Sierra Nevada. It works like this: If you are water in late spring snowmelt, the first impediment to your flow will be a privately owned dam. If you are a salmon swimming upstream from the sea, the first obstacle will be a federally owned dam. This is a simplification, but the general rule of thumb is that private non-federal dams are located at high elevations, while the larger federal dams are

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17. *See generally* Bauer, *Bringing Water Markets Down to Earth*, *supra* note 11; Bauer, *Slippery Property Rights*, *supra* note 11, at 111; *see generally* BAUER, SIREN SONG, *supra* note 11; Bauer, *Dams and Markets*, *supra* note 11, at 584.

18. Carl J. Bauer, *Water Conflicts and Entrenched Governance Problems in Chile's Market Model*, 8 WATER ALTERNATIVES 147 (2015).

19. The converse can also be true. The people and groups who craft institutional arrangements have the opportunity to infuse new institutional arrangements with their values.

20. Some members of the U.S. judiciary explicitly rely on this mechanism to help decide disputes in a manner that changes the bargaining position of litigants to negotiate further. *Cf.* Ward Farnswoth, *Do Parties to Nuisance Cases Bargain after Judgment? A Glimpse Inside the Cathedral*, 66 CHI. L. REV. 373, 421 (1999) (finding that in a sample of 20 cases, litigants rarely bargained after specific relief was granted, even if bargaining would be mutually beneficial).

located downstream at lower elevations. This division has implications for rivers, electricity generation, and water supply because the laws governing non-federal and federal dams are so different. And each set of rules has its corresponding barriers and opportunities for adaptation.

On the western slopes of the Sierra Nevada, from an elevation of 1,000 feet to the peaks of the mountains, there are over 150 hydropower dams, providing the lion's share of the state's hydroelectric generation, though lacking in storage capacity.[21] Almost none of these are federal dams. They are dominated by mid-sized dams, whose installed capacity ranges in tens rather than hundreds of megawatts. And they are owned and operated primarily by private utilities and independent private operators, along with a handful of publicly owned utilities. Altogether, high-elevation dams account for most of the generating capacity in California (approximately 74 percent).[22]

At lower elevations, and in the Cascades range in the far north of the state of California, federal hydropower dams control the bulk of generation capacity and water storage. These dams were built primarily with water delivery, flood control, and agriculture in mind, with hydroelectric generation as a secondary purpose.[23]

No hydropower dam in California is governed only by federal law. Nor is one governed only by state law. Instead each dam is governed by interconnected federal and state water law, environmental law, and energy law. Although the federal government has always played a strong role in hydropower governance in California[24] through its powers to regulate commerce on navigable rivers of the United States, its preemption of state hydroelectric law through the Federal Power Act, and its role as owner of the largest dams in the state, the state is a steward of the public trust in rivers, responsible for water quality, and the determination, allocation, and governance of water rights.

21. ASPEN ENVTL GROUP & M-CUBED, POTENTIAL CHANGES IN HYDROPOWER PRODUCTION FROM GLOBAL CLIMATE CHANGE IN CALIFORNIA AND THE WESTERN UNITED STATES 3, 7 (2005), http://www.energy.ca.gov/2005publications/CEC-700-2005-010/CEC-700-2005-010.PDF [https://perma.cc/E5U2-PARS] (drafted in support of the 2005 Integrated Energy Policy Report Proceeding).

22. MARION GUEGAN, KAVEH MADANI, & CINTIA B. UVO, CAL. ENERGY COMM'N, CLIMATE CHANGE EFFECTS ON THE HIGH-ELEVATION HYDROPOWER SYSTEM WITH CONSIDERATION OF WARMING IMPACTS ON ELECTRICITY DEMAND AND PRICING 3 (2012).

23. Maurice Roos, a hydropower expert at the California Department of Water Resources, recalled that a lower elevation hydropower dam was built with a wide and shallow pool in order to supply water at more ideal (warmer) temperatures for rice growers in the Sacramento area. Interview by Sonya Ziaja with Maurice Roos, California Department of Water Resources, May 4, 2015, Sacramento, CA (on file with author).

For more background on large federal dams, see DAVID P. BILLINGTON, DONALD C. JACKSON, & MARTIN V. MELOSI, THE HISTORY OF LARGE FEDERAL DAMS: PLANNING, DESIGN, AND CONSTRUCTION IN THE ERA OF BIG DAMS (2005).

24. The federal government though has not always exercised its power over hydropower in the West, and at times has doubted its existence. *See* MARTIN MELOSI, COPING WITH ABUNDANCE: ENERGY AND ENVIRONMENT IN INDUSTRIAL AMERICA (1985). Disputes over the ability and legitimacy of the federal government to regulate the operations of hydroelectric dams have been a major part of hydropower history since private dams were first developed in the late 19th century.

B. How are Federal and Non-federal Dams Governed?

Federal hydropower dams each have operating rules that are the product of federal and state interagency cooperation and authorization by the U.S. Congress. The hydroelectric dam at Shasta, for example, was originally a state project; but due to lack of funds during the Great Depression, the design was transferred to federal ownership—i.e., the federal government ended up paying for, building, and maintaining the state-planned dam. The United States Bureau of Reclamation (Bureau of Reclamation) continues to be responsible for Shasta's operation. Reclamation does not act alone, though. Nor does it have the final say in operations. Like all other large federal dams in the state, Shasta is a multipurpose dam. It was designed for flood control, irrigation, water storage, and hydroelectric power supply. Flood control rules are set for all federal dams by the Army Corps of Engineers.[25] California Department of Water Resources is responsible for coordinating irrigation diversions and hydrologic forecasting.[26] California Department of Fish and Wildlife coordinates with Reclamation to decide on appropriate releases of water from the dam.[27] And finally, the National Weather Service, although not directly involved in the operation of the dam, provides hydrologic forecasts, which are key inputs for reservoir operations decision-making.[28] Electricity pricing from Shasta is, in part, governed by an agreement[29] between the Western Area Power Administration (part of the U.S. Department of Energy)[30] and the California Independent System Operator Corporation (a heavily regulated nonprofit, responsible for balancing most of California's electricity grid).[31]

Although water governance is generally left to the states in the U.S., hydropower law for non-federal dams is an exception.[32] Non-federal hydropower

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25. *See* Water Control Management, 33 C.F.R. § 222.5(f)(1) (2017). *See also* Flood Control Act of 1944, Pub. L. 78, 58 Stat. 890, 33 U.S.C. 709 (2012).

26. CAL. WATER CODE §§ 225–238 (West 2017).

27. Letter from Kirk C. Rodgers, Reg'l Dir., Bureau of Reclamation, Dep't of the Interior, to Lester Snow, Dir., Cal. Dep't of Water Res. (Feb. 10, 2006) (referring to Principles of Agreement For Collocation of California Department of Water Resources State Water Project Operations Control Office and United States Bureau of Reclamation Central Valley Operations Office), http://www.usbr.gov/mp/cvo/data/Principles%20of%20Agreement.pdf [https://perma.cc/XRH5-BW9H].

28. Harry R. Glahn & David P. Ruth, *The New Digital Forecast Database of the National Weather Service*, 84 BULL. OF THE AM. METEOROLOGICAL SOC'Y 195 (2003).

29. Press Release, Jennifer Neville, California ISO, Western Agree Upon Locational Pricing for CVP Federal Hydropower, Increasing Value of Hydropower Stock in California, Western Area Power Administration (Dec. 3, 2015), https://www.wapa.gov/newsroom/NewsFeatures/2015/Pages/CVP-hyropower-increased-value.aspx [https://perma.cc/VL6G-8C4F].

30. *See About WAPA*, WESTERN AREA POWER ADMIN., https://www.wapa.gov/About/Pages/About.aspx [https://perma.cc/4VJD-ENYU].

31. *See About Us*, CAL. ISO, http://www.caiso.com/about/Pages/default.aspx [https://perma.cc/U23U-4CXB]; Ziad Alaywan & Jack Allen, *California Electric Restructuring: a Broad Description of the Development of the California ISO*, 13 *IEEE TRANSACTIONS ON POWER SYSTEMS* 1445 (1998).

32. *See* Reed Benson, *Deflating the Deference Myth: National Interests vs. State Authority under Federal Laws Affecting Water Use*, 2006 UTAH L. REV. 241 (2006) (challenging the widely held misconception that the federal government has always deferred to states for water governance, and relying in part on the Federal Power Act as an example of "low deference" to states for water management).

dams—which include state owned dams, municipal, and privately owned dams—are nearly all regulated through a federal licensing process that determines the operating rules of the dam for a period of 30–50 years.[33] The Federal Energy Regulatory Commission (FERC),[34] under the Federal Power Act (FPA), has primary responsibility for developing, granting or denying, and renewing these licenses.[35] Consideration of uses other than hydroelectric generation is built into the FPA and other authorizing statutes applicable to non-federal hydropower—bringing state and federal interagency cooperation with it.[36] Under the FPA, issued licenses must be "best adapted to a comprehensive plan for improving or developing a waterway,"[37] and ultimately be in the public interest.[38] 1986 amendments to the FPA expand on this requirement, mandating "equal consideration" of energy, environment, recreation, and public health.[39] If the dam is on federal land, the agency that manages the land can impose conditions on licenses to maintain the purpose of the land (protection/use).[40] Additionally, if a dam is located on federal land, under the 2005 amendments to the FPA,[41] parties to pending licenses can propose alternative conditions that FERC must accept if they

33. 16 U.S.C § 808(e) (2012).

34. The FPA is the successor to the Federal Power Commission. *See* Federal Water Power Act, ch. 285, 41 Stat. 1063 (1920) (codified as amended at 16 U.S.C. § 791a (2012)). *See also* Department of Energy Organization Act, Pub. L. No. 95-91, 91 Stat. 565, 582–87 (1977) (codified as amended at 42 U.S.C. §§ 7171–77 (2012)).

35. 16 U.S.C. §§ 792, 797 (2012).

36. 2 ENERGY LAW AND TRANSACTIONS § 53.02 (Michael A. Swiger et al. eds., 2016).

37. 16 U.S.C. § 803(a).

38. Udall v. Fed. Power Comm'n, 387 U.S. 428, 440 (1976).

39. Electric Consumers Protection Act of 1986, Pub. L. No. 99-495, 100 Stat. 1243 (codified as amended at 16 U.S.C. § 797(e) (2012)) (stating that FERC "shall give equal consideration to the purposes of energy conservation, the protection, mitigation of damage to, and enhancement of, fish and wildlife (including related spawning grounds and habitat), the protection of recreational opportunities, and the preservation of other aspects of environmental quality"). *See also* Nat'l Wildlife Fed'n v. Fed. Energy Regulatory Comm'n, 80 F.2d 1505, 1507, 1513 (9th Cir. 1986) (interpreting the Federal Power Act, equal consideration does not mean equal treatment).

For an exploration of FERC's reluctance after the passage of the EPCA to take on its "secondary mission" of environmental protection, and an assessment of interagency lobbying among federal wildlife and environmental agencies and FERC, see J.R, DeShazo and Jody Freeman, *Public Agencies as Lobbyists*, 105 COLUM. L. REV. 2217, 2223 (2005) (also noting that "[t]hough ECPA made this requirement[, i.e., equal consideration to non power values in licensing decisions,] explicit, FERC was arguably bound to such equal consideration already, at least under the FPA as it had been construed by the courts, . . . Yet FERC had, for a variety of reasons, long resisted doing so.") (internal citations omitted). *See* Ann E. Carlson & Andrew Mayer, *Reverse Preemption*, 40 ECOLOGY L.Q. 583, 593 (2013) (discussing FERC's expanded environmental mission under the 1986 amendments and the important role of state intervention in FERC decision-making to hold it to new environmental requirements); *see also* Michael C. Blumm & Viki A. Nadol, *The Decline of the Hydropower Czar and the Rise of Agency Pluralism in Hydroelectric Relicensing*, 26 COLUM. J. ENVTL. L. 81, 88 (2001) (discussing FERC's failure to respond to its environmental duties, especially under the EPCA); George W. Sherk, *Approaching a Gordian Knot: The Ongoing State/Federal Conflict Over Hydropower*, 31 LAND & WATER L. REV. 350, 356 (1996) (discussing FERC's approach to consultation and consideration requirements).

40. 16 U.S.C. § 797(e) (2012).

41. Energy Policy Act of 2005, Pub. L. No. 109-58. 119 Stat. 594.

provide "adequate" protection and cost less or improve operating conditions.[42] Regardless of the location of the dam, the federal fisheries agencies (U.S. Fish and Wildlife Service and the National Marine Fisheries Service) can impose terms in licenses for the construction and operation of fish passageways.[43] Since 2005, parties can propose alternative conditions for fisheries mitigation and protection that FERC must accept if they offer "equivalent" protection and cost less or improve energy output.[44] Federal and state fish and wildlife agencies are also empowered to propose conditions "in order to adequately and equitably protect, mitigate damages to, and enhance, fish and wildlife [and associated habitat]."[45]

The FPA also includes a "savings clause"—modeled after that of the 1902 Reclamation Act—that reserves the right of the states to regulate water.[46] Although historically, judicial interpretation of the two clauses required more deference from Reclamation than from FERC to state law and policy,[47] the Clean Water Act provides another opening for state input and control over water quality

42. 16 U.S.C. § 823(d) (2012).

43. 16 U.S.C. § 811 (2012).

44. 16 U.S.C. § 823(d). Third parties can also demand quasi judicial hearing on any disputed issue of material fact. *See* 16 U.S.C. § 797(e) (2012). For an analysis of the implementation of hearings and stakeholder views of the collaborative aspects of the Energy Policy Act of 2005, see generally U.S. GOV'T ACCOUNTABILITY OFFICE, HYDROPOWER RELICENSING: STAKEHOLDERS' VIEWS ON THE ENERGY POLICY ACT VARIED, BUT MORE CONSISTENT INFORMATION NEEDED (2010), http://www.gao.gov/products/GAO-10-770 [https://perma.cc/DSA4-P9RS].

45. 16 U.S.C. § 803(j)(1) (2012). FERC however only needs to consider and respond in writing to suggestions. *See* 16 U.S.C. § 803(j)(2). *See supra* note 39 and accompanying text for citations discussing the interplay between environmental agencies and FERC. For more on the Energy Policy Act of 2005, see generally Michael D. Hornstein & J.S. Gebhart Stoermer, *The Energy Policy Act of 2005: PURPA Reform, the Amendments and their Implications*, 27 ENERGY L.J. 25 (2006).

46. 16 U.S.C. § 821 (2012) (stating that states have authority to regulate "relating to control, appropriation, use, or distribution of water used in irrigation or for municipal or other uses, or any vested right acquired therein"). And see Fed. Power Comm'n v. Oregon, 349 U.S. 435 (1955), for early treatment of federal preemption. For histories of caselaw dealing with federal versus state jurisdiction over water for hydroelectric power, see generally Daniel Pollak, Note, S.D. Warren *and the Erosion of Federal Preeminence in Hydropower Regulation*, 34 ECOLOGY L.Q. 763 (2007); *see also* Roderick E. Walston, *State Regulation of Federally-Licensed Hydropower Projects: The Conflict between California and First Iowa*, 43 OKLA. L. REV. 87 (1990) [hereinafter Walston, *State Regulation of Federally-Licensed Hydropower Projects*] (Walston, who represented California in lawsuits against FERC, argues that the line of cases stemming from *First Iowa* were wrongly decided); Roderick E. Walston, *California v. Federal Energy Regulatory Commission: New Roadblock to State Water Rights Administration*, 21 ENVTL. L. 89 (1991) [hereinafter Walston, *California v. Federal Energy Regulatory Commission*]; M. Curtis Whittaker, *The Federal Power Act and Hydropower Development: Rediscovering State Regulatory Powers and Responsibilities*, 10 HARV. ENVTL. L. REV. 135 (1986) (arguing that states have "a latent authority" over small hydropower development).

47. California v. Fed. Energy Regulatory Comm'n, 495 U.S. 490, 503–05 (1990) (referred to as the Rock Creek Decision, rejecting California's argument that the FPA savings clause required the same deference to state water law as the Reclamation savings clause); *see also* Sayles Hydro Ass'n v. Maughan, 985 F.2d 451 (1993) (emphasizing the Rock Creek decision and holding that the only permissible state regulation that could be imposed on federally licensed dams was to determine proprietary water rights). For strong critiques of the Rock Creek Decision, see Walston, *State Regulation of Federally-Licensed Hydropower Projects*, *supra* note 46 (addressing the Ninth Circuit's decision); *see also* Walston, *California v. Federal Energy Regulatory Commission*, *supra* note 46 (addressing the Supreme Court decision); A. DAN TARLOCK, LAW OF WATER RIGHTS AND RESOURCES § 9:20 (2016).

considerations in FERC licensing. Specifically, Section 401 of the Clean Water Act allows states to impose conditions on FERC licenses so that state water quality standards are met.[48] Case law interpreting the application of Section 401 to FERC licenses has gradually expanded the powers of states (as against the federal energy agency) to regulate water quality for environmental and aesthetic goals.[49]

What is notable about how state and federal law interact for both federal and non-federal dams is that the law that governs hydropower operations in California is not uniform—no set of rules for a hydropower generating station is exactly the same set of rules for any other hydropower generation station. There is overlapping jurisdiction across multiple federal and state agencies. Which rules apply depend on where a dam is located, how large it is, what entity owns the dam, what purposes it was built for, and the particulars of the ecosystem where it is situated.[50] The idea that the rules for each dam are "to at least some extent . . . unique" is reflected in FERC's policy statement encouraging settlement agreements for licensing and issues outside of FERC's direct jurisdiction:

> Hydroelectric Licensing proceedings under Part I of the Federal Power Act (FPA) are multi-faceted and complex. These proceedings involve the balancing of many public interest factors, as well as consideration of the views of all interested groups and individuals. Moreover, since the physical design, environmental impact, and history of every project is different, each licensing proceeding is, to at least some extent, unique.[51]

In short, while there are similarities across dams, the particular combination of operating rules for each, the means to change those rules, and the set of stakeholders and concerns for each, are all different.

C. Distribution of Barriers to Climate Adaptation Vary by Geography

A consequence of multijurisdictional hydropower governance is that the resulting distribution of barriers and opportunities for adaptation to climate change impacts vary by geography. For example, higher elevation dams, and the stretches of river that flow to and from them, are more likely to be susceptible to the

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48. 33 U.S.C. § 1341(a)(1) (2012).

49. PUD No. 1 v. Wash. Dep't of Ecology, 511 U.S. 700, 722–23 (1994) (FERC must accept 401 conditions including those related to fish protection and aesthetic goals). *See* Pollak, *supra* note 46 (discussing SD Warren); *see also* Carlson & Mayer, *supra* note 39, at 586–87 (arguing that "reverse preemption", or power of states to check federal agencies through CWA § 401, "may guard against . . . the power of specialized agencies like the Federal Regulatory Commission . . . , the Department of the Interior . . . , and the Army Corps of Engineers. These agencies may develop institutional cultures that favor particular interest groups with which they have frequent contact. The reverse preemption provisions ensure that the voices of states with strong environmental concerns are heard.").

50. Further operational rules—for example deploying small hydrogeneration to repower from a "black start"—depend on electricity demand and supply, as coordinated through Balancing Authorities. *See, e.g.,* FED. ENERGY REGULATORY COMM'N, ENERGY PRIMER: A HANDBOOK OF ENERGY MARKET BASICS (2015), https://www.ferc.gov/market-oversight/guide/energy-primer.pdf [https://perma.cc/S87A-BT4E].

51. FED. ENERGY REGULATORY COMM'N, NO. PL06-5-000, POLICY STATEMENT ON HYDROPOWER LICENSING SETTLEMENTS (2006).

challenges posed by state law and FERC, while lower elevation federal dams and stretches of river are dominated by constraints from Army Corps rules regarding flood control.

While there are multiple theories and definitions of climate adaptation and adaptive governance, for purposes of this paper, I will employ the definition of climate adaptation used by the California Energy Commission (CEC), since it has been a major funding agency of engineering models of the hydropower system and of climate adaptation-related research. The Energy Commission is part of an interagency Energy Adaptation Working Group that also includes representatives from the California Public Utilities Commission, California Natural Resources Agency, and the Governor's Office of Emergency Services. The group defines climate adaptation for the energy sector as: "Planning and implementation to provide reliable and accessible energy in California, accounting for current and projected effects of climate change, and including iterative learning mechanisms to refine efforts as climatic conditions and scientific knowledge evolve."[52] A joint Energy Commission and CPUC public workshop held in June 2016 on climate adaptation for the energy sector focused on lessons from current real-world attempts to alter energy systems and plan for climate change.[53] Two aspects of adaptation to climate change were common throughout the presentations. One of these was the need for flexibility in decision-making. The second was the need to consider interconnections across sectors and geography.[54] I will focus on these two elements of adaptation—flexibility and cross-sector considerations—to help describe the potential legal barriers to climate adaptation in California hydropower.

1. Lack of Flexibility and Coordination in FERC Licensing

FERC relicensing has several attributes that make it ill-suited to flexible decision-making and interconnected considerations. A major barrier to flexibility is the duration of the licenses.

The FPA requires FERC operating licenses be issued for a minimum of 30 and a maximum of 50 years.[55] It is possible that the time period for relicensing—really a period of non-interference—was set at 50 years because that was the anticipated time for the licensee to have recovered its initial investment.[56] It also allows for an entire generation of managers and operators to work under the same set of rules without, in theory, needing to anticipate change. The origins of the 50

52. CAL. ENERGY COMM'N, 2016 INTEGRATED ENERGY POLICY REPORT UPDATE 117–18 (2017), http://docketpublic.energy.ca.gov/PublicDocuments/16-IEPR-01/TN216281_20170228T131538_Final_2016_Integrated_Energy_Policy_Report_Update_Complete_Repo.pdf [https://perma.cc/EKM2-EHJC] [hereinafter CAL. ENERGY COMM'N, 2016 INTEGRATED ENERGY POLICY REPORT UPDATE].

53. CAL. ENERGY COMM'N, JOINT IEPR WORKSHOP ON CLIMATE ADAPTATION AND RESILIENCY FOR THE ENERY SECTOR (2016), http://docketpublic.energy.ca.gov/PublicDocuments/16-IEPR-04/TN212477_20160727T135220_Transcript_of_the_06212016_Joint_IEPR_Workshop_on_Climate_Adapt.pdf [https://perma.cc/F67W-HTJC].

54. *See* CAL. ENERGY COMM'N, 2016 INTEGRATED ENERGY POLICY REPORT UPDATE, *supra* note 52, at 23, 29–30, 42–43, 59, 67.

55. 16 U.S.C § 808 (2012).

56. *See* Whittaker, supra note 46, 147–50 (discussing the early history of the FPA and President Roosevelt's insistence that permits "be subject to the right of the Government to fix a term for their duration") (internal quotations omitted).

year permit, though, has its roots in early twentieth century debates over whether the federal government should, or even did, have jurisdiction to regulate hydropower dams. In the late nineteenth century, hydroelectric power was private. As part of a lengthy debate over the validity of public regulation of private hydroelectric power in the first two decades of the twentieth century, the U.S. Forest Service, and later the U.S. Geologic Survey, became responsible for issuing "right of way" permits that allowed private dams to be built and operated on federal land.[57] Private power companies lobbied against the permit system and for "perpetual leases."[58] Although they were ultimately unsuccessful, the permit program eventually was amended to allow 50-year grants.[59] Congress did not adjust the 50-year minimum until Regan-era amendments to the Public Utility Regulatory Policies Act (PURPA)[60] and the FPA shortened it to 30 years for most projects.

The irony of having a lengthy period of relative legal stability is that while the rules remain the same for that period, the climatic conditions will not. In a sense, the basic idea of FERC relicensing—alternating periods of stability with comprehensive review for relicensing—is harmonious with theories of adaptive governance.[61] But the timescale is too long. For example, over a period of 30–50 years,[62] downscaled climate models for Sacramento show an annual mean temperature increase of approximately 4.5 degrees Fahrenheit, with nearly five times the number of extreme heat days (above 103.9 degrees Fahrenheit).[63] These temperature changes have a significant impact on demand for energy, availability of water, timing and type of precipitation, as well as changing critical habitat conditions.[64] Put another way, climate change is altering the hydrology of California[65] faster than FERC dams are being relicensed.

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57. MELOSI, *supra* note 24, at 81.

58. *Id*. Lobbying and procedural maneuvering in the U.S. House of Representatives almost resulted in such perpetual and non-conditional leases for seventeen private hydropower projects, had it not been for President Taft vetoing similar legislation. *See* 2 ENERGY LAW AND TRANSACTIONS § 53.02 (2017).

59. MELOSI, *supra* note 24, at 82.

60. Public Utility Regulatory Policies Act, Pub. L. No. 95-617, 92 Stat. 3117 (1978).

61. *See* Robin K. Craig & J.B. Ruhl, *Designing Administrative Law for Adaptive Management*, 67 VANDERBILT L. REV. 1, 3–16 (2014).

62. Beginning in 2005, with an annual mean temperature derived from observed data from 1950–2005, and with projections aligned with RCP 8.5. The annual mean described above is an average of ten climate models, selected by the California Department of Water Resources. *See Annual Averages*, CAL-ADAPT, http://beta.cal-adapt.org/tools/annual-averages/#climatevar=tasmax&scenario=rcp85&lat=38.58&lng=-121.46&boundary=locaModelGrid&units=fahrenheit (last visited Apr. 27, 2017).

63. *See Extreme Heat*, CAL-Adapt, http://beta.cal-adapt.org/tools/extreme-heat/#climatevar=tasmax&scenario=rcp45&lat=38.58&lng=-121.46&boundary=locaModelGrid&units=fahrenheit (last visited Apr. 27, 2017) (using RCP 8.5).

64. *See* CAL. ENERGY COMM'N, 2015 INTEGRATED ENERGY POLICY REPORT 241–44 (2016).

65. Climate change is decreasing the Sierra snowpack that feeds the state's major rivers in the spring and summer, increasing evapotranspiration from warmer temperatures, and affecting atmospheric rivers. *See generally* Michael Dettinger, Bradley Udall & Aris Georgakakos, *Western Water and Climate Change*, 25 ECOLOGICAL APPLICATIONS 2069 (2015); *see also* CAL. ENERGY COMM'N, 2015 INTEGRATED ENERGY POLICY REPORT (2016). For detailed atmospheric river and climate change studies, see generally David A. Lavers et al., *Climate Change Intensification of Horizontal Water Vapor Transport in CMIP5*, 42 GEOPHYSICAL RES. LETTERS 5617 (2015); Michael D. Dettinger, *Historical and Future Relations Between Large Storms and Droughts in California*, 14 S.F. ESTUARY & WATERSHED SCI. 1 (2016).

Additionally, most FERC-licensed dams were initially licensed prior to the 1970s, and operating under rules written prior to the passage of the Endangered Species Act (1973), the Clean Water Act (1972), the National Environmental Protection Act (1970), and their procedurally-demanding state law analogs (the California Endangered Species Act, or CESA, and the California Environmental Quality Act, or CEQA, both passed in 1970).

There are two mechanisms that in theory allow the licenses to be more flexible tools. The FPA and FERC regulation allows for the inclusion of "reopener clauses" in licenses, which allow terms to be renegotiated during the 30–50 year term.[66] And, licensees can request that multiple dams be considered at once, such that licensing is coordinated at a basin-wide scale rather than on a case-by-case basis. In practice though, it has been left to the discretion of the licensees to request that these terms be included; and licensees have largely not opted to take on the extra challenge of coordinating across dam owners or including reopener clauses.

Similarly, even where the rules offer FERC discretion to consider climate change, the agency has been reluctant to do so. Viers, for example, describes how a group of stakeholders used the formal process for petitioning the agency to consider additional scientific information in the relicensing of Yuba-Bear Drum-Spaulding hydroelectric facilities.[67] This was the Integrated Licensing Process (ILP). ILP is a very recent addition to the FERC licensing process that was added through the 2005 Energy Policy Act Section 241. FERC rejected the request, stating that climate change models have insufficient accuracy to inform license conditions.

As a result, the status quo for most FERC licenses is to only consider impacts to the river immediately where the dam is located, and not upstream or cumulative downstream impacts. Since most high-elevation dams are FERC licensed dams, the long-lasting rules in licensing come with miles of downstream river to absorb their consequences.

2. Inflexible Planning for Multiple Objectives in Army Corps Flood Control Rule Curves

There are strict guidelines developed by the Army Corps of Engineers for each federal dam designed for flood control[68] that proscribes the maximum amount of water allowable at a given dam, based on the date. From an adaptation standpoint there are three things that are important about rule curves. First, they do not offer much, if any, room for variation or discretion. Some rule curves are more

66. *See* Pollak, *supra* note 46, at 766, 784. Reopener clauses have also been supported by Congress. "The Committee believes that the Commission should have authority to ensure that licenses reflect current information concerning the need to protect fish and wildlife. The legislation does not change existing law, including case law, governing FERC authority to modify licenses during their term." H.R. REP. NO. 99-507, at 32 (1986).

67. *See generally* Josh Viers, *Hydropower Relicensing and Climate Change*, 47 J. AM. WATER RESOURCES ASS'N 655 (2011).

68. Army Corps rule curves also can apply to non-federal dams where the federal government provides partial financial support (i.e., non-federal dams with federal cost share like Oroville) and can be incorporated into FERC licenses where applicable. *See, e.g.,* Oroville-Federal Flood Control Operating Criteria, DEPT. WATER RES., http://www.water.ca.gov/swp/facilities/Oroville/FCRules.cfm [https://perma.cc/SC8Z-U35G] (text taken from California Water Plan Update Bulletin 160-98).

flexible than others. The conditions considered in rule curves are different from dam to dam. Shasta's includes greater flexibility for refill (i.e, can begin refill earlier in the year), and ties the rate of refill to observed inflows, for example. However, New Bullards Bar's rule curve is static and anticipates hypothetical flows from another dam (Marysville), which was never constructed.[69] But what is consistent across Army Corps rule curves is that they do not take short- and medium-term forecasts into account.[70] Second, rule curves are based on historical data. For example, the curve for New Bullards Bar Reservoir was based on one "wet" year (1954) and one "near normal" year (1952).[71] Third, dam operators are required to follow the rule curve. In effect, this means that when water supply—whether for environment, energy, or human consumption—is pitted against flood control, flood control wins, even if the likelihood of flood is near zero.[72]

Post-1959, when the Army Corps published a master manual on reservoir regulation,[73] the intent had been to review and update rule curves every three to five years.[74] However, there was insufficient funding available to cover the costs of compliance with NEPA to update rule curves. In the absence of reliable funding, the Corps has not regularly updated rule curves.[75]

69. *See* U.S. ARMY CORPS ENG'RS, NEW BULLARDS BAR DAM AND RESERVOIR, NORTH YUBA RIVER, CALIFORNIA: WATER CONTROL MANUAL (2004); Ann Willis et al., *Climate Change and Flood Operations in the Sacramento Basin, California*, 9 S.F. ESTUARY & WATERSHED SCI. 1, 14 (2011).

70. *See*, *e.g.,* JUAN B. VALDES & JUAN B. MARCO, U.S.-ITALY RESEARCH WORKSHOP ON THE HYDROMETEROLOGY, IMPACTS, AND MGMT. OF EXTREME FLOODS, MANAGING RESERVOIRS FOR FLOOD CONTROL 1 (1995), http://www.engr.colostate.edu/ce/facultystaff/salas/us-italy/papers/43valdes.pdf [https://perma.cc/R2VE-7GKB] (discussing the early history of the interest in the "application of optimization and forecasting techniques to water resource systems" and the flood control techniques for reservoirs used by the US Army Corps of Engineers).

71. U.S. ARMY CORPS ENG'RS, NEW BULLARDS BAR RESERVOIR, NORTH YUBA RIVER, CALIFORNIA: REGULATION FOR FLOOD CONTROL 5–12 (1972) (discussing characteristics of the climate in the basin).

72. The problem of maladaptive flood control rules is more visible to the public than the long duration of static FERC licenses, because the result is releasing water in dry years. The past several years of drought have made Californians particularly sensitive to how much water is stored in their reservoirs, especially if those reservoirs are releasing water rather than maintaining it for long and dry summers. *See* Ryan Sabalow, Phillip Reese & Dale Kasler, *Sacramento Agencies Ask: Why Release Water from Folsom Lake During Drought?*, SACRAMENTO BEE (Feb. 15, 2016), http://www.sacbee.com/news/state/california/water-and-drought/article60419396.html [https://perma.cc/N7PK-UJSE]; Annie Snider*, Dusty Federal Rules Complicate Water Management in Parched West*, E&E NEWS. (Feb. 27, 2014), http://www.eenews.net/stories/1059995262 [https://perma.cc/42CM-E67U]; Barbara Arrigoni, *Biological Opinion Slows Oroville Dam Facilities Relicensing Process*, CHICOER NEWS (Oct. 5, 2015), http://www.chicoer.com/article/NA/20151005/NEWS/151009847 [https://perma.cc/3HUC-98KK]. These popular news stories have delved into the normally wonky world of federal administrative law to report on tension between rules for water supply and flood control in dams throughout the state.

73. U.S. ARMY CORPS ENG'RS, MASTER MANUAL OF RESERVOIR REGULATION: SACRAMENTO RIVER BASIN, CALIFORNIA (1959).

74. Willis, *supra* note 69, at 3.

75. *Id*. It should be noted the rule curves for Folsom are currently being reconsidered. *See*, *e.g.,* Sabalow, Reese & Kasler, *supra* note 72.

III. ENGINEERING MODELS ON CHANGING HYDROPOWER GOVERNANCE

"All models are wrong, but some are useful."

—George E. P. Box

Why focus on engineering optimization models, given the state of hydropower governance? Over the past decade and a half, there has been a proliferation of research tackling barriers to climate adaptation for hydropower dams, suggesting alternative ways forward for dam operations[76] and illuminating the interactions between science-informed decision-making and law for water management. Roughly, there are three approaches. The first suggests that the prevailing laws governing hydropower are maladaptive and that modeling work is key to reforming those laws.[77] This group is predominately comprised of engineers and environmental scientists.[78] The second line of reasoning, dominated by lawyers, portrays science, and by extension hydrologic modeling and other tools, as captured by disputants in legal battles over water rights.[79] And the third approach, from multidisciplinary social scientists, suggests that a "culture of conservatism," or general risk aversion, among water managers has prevented them from incorporating short-term climate forecasts, but that changes within organizational culture may allow for future managers to incorporate climate information into hydropower management practices.[80]

Critiques based on engineering models are notable because California has disproportionately solicited and funded research from these fields on adapting its

76. This was the topic for a three-day conference on "Operating Reservoirs in Changing Conditions" held by the Environmental and Water Resources Institute (EWRI) of the American Society of Civil Engineers held in Sacramento, California. It was co-sponsored by the US Army Corps of Engineers, Reclamation, California Department of Water Resources, The Northern Colorado Water Conservancy District, and the Tennessee Valley Authority. The complete set of 43 studies presented at the conference are published in AMERICAN SOC'Y OF CIVIL ENG'RS, OPERATIONS MANAGEMENT CONFERENCE: OPERATING RESERVOIRS IN CHANGING CONDITIONS (Darell Zimbelman & Werner C. Loehlein eds., 2006).

77. *Id*.

78. *See, e.g.,* K. P. Georgakakos et al., *Integrating Climate-Hydrology Forecasts and Multi-Objective Reservoir Management for Northern California*, 86 EOS 122 (2005); JEFFREY MOUNT ET AL., REGIONAL AGREEMENTS, ADAPTATION, AND CLIMATE CHANGE: NEW APPROACHES TO FERC LICENSING IN THE SIERRA NEVADA, CALIFORNIA (2007), http://watershed.ucdavis.edu/pdf/Mount-et-al-FERC-081707.pdf [https://perma.cc/XSL3-DNH2]; Viers, *supra* note 67; Willis, *supra* note 69.

79. *See, e.g.*, HOLLY DOREMUS & A. DAN TARLOCK, WATER WAR IN THE KLAMATH BASIN: MACHO LAW, COMBAT BIOLOGY, AND DIRTY POLITICS (2008).

80. *See generally* Steve Rayner, Denise Lach & Helen Ingram, *Weather Forecasts are for Wimps: Why Water Resources Managers do not Use Climate Forecasts*, 69 CLIMATIC CHANGE 197 (2005); Denise Lach, Steve Rayner & Helen Ingram, *Taming the Waters: Strategies to Domesticate the Wicked Problem of Water Resources Management*, 3 INTL. J. WATER 1 (2005). These three approaches are not necessarily inconsistent, however, as the context and concerns for each group are distinct. Doremus and Tarlock were specifically concerned with how science is wielded in ongoing litigation; the engineering group is not necessarily advocating any particular use of reservoirs over others; and the social science group was concerned about why or why not seasonal climate forecasts were being adopted by water managers. In other words, the overarching questions each group is trying to answer is different.

water and energy systems,[81] and because engineering optimization models offer a peculiar set of prescriptions that relate more to their method of diagnosis than the underlying illness.

After modeling the hydropower system, or parts of it, to include more "rational" rules, engineering modelers tend to first note how much better the system would work if the institutional arrangements in reality were more like those in the model, and recommend significant changes to those arrangements without regard to existing legal or political context. What is missing in this kind of analysis is an understanding of the institutional arrangements for changing the rules that govern hydropower dams. If the models were more complete, or at least more faithful, in their representation of the institutional structures undergirding hydropower systems, it might be difficult to reasonably suggest major changes to those rules.

Curiously, a few engineering, and related environmental science, studies *do* make the point that the barriers to adaptation are, at root, political, and therefore may not be easy to overcome or alter. Viers, for example, after challenging FERC for its "poor reasoning" and "risky decision" to reject the inclusion of climate change considerations in its relicensing of a dam, notes that the agency "is probably challenged to meet its regulatory mandate while balancing many political and economic interests."[82] Similar observations are made by Mount and others.[83] The idea that barriers to adaptation stem from "messy" governance is inherent in the use of the CALVIN model's "optimistic representation of what can be done institutionally."[84] And an early engineering paper on managing reservoirs for flood control using optimization notes that "It appears that legal, socio-economic, and construction funding problems place so many constraints on reservoir capacity decision that, in practice, hydrologic and purely technological issues remain secondary."[85]

However, after pointing out the political, social, and financial problems of overcoming the identified barriers, these scholars rarely suggest political, social, or financial solutions.[86] Rather, they turn to more modeling as a path forward.[87]

81. For detailed information on research funding through the California Energy Commission's administration of the PIER grant program, see *Research and Development Reports and Publications*, CAL. ENERGY COMM'N, http://www.energy.ca.gov/research/reports_pubs.html (last visited April 27, 2017).

82. Viers, *supra* note 67, at 3, 4.

83. MOUNT ET AL., *supra* note 78, at 5, 13.

84. CAL. ENERGY COMM'N, CLIMATE CHANGE ADAPTATIONS FOR LOCAL WATER MANAGEMENT IN THE SAN FRANCISCO BAY AREA 1–2 (2005), http://www.energy.ca.gov/2012publications/CEC-500-2012-036/CEC-500-2012-036.pdf [https://perma.cc/8BDB-KKP8].

85. VALDES & MARCO, *supra* note 70, at 5–6.

86. *Cf.* Viers, *supra* note 67.

87. *See, e.g.,* MOUNT ET AL., *supra* note 78; GEORGAKAKOS ET AL., *supra* note 78; Stacy K. Tanaka et al., *Climate Warming and Water Management Adaptation for California*, 76 CLIMATIC CHANGE 361 (2006); Josue Medellin-Azuara et al., *Adaptability and Adaptations of California's Water Supply System to Dry Warming,* 87 CLIMATIC CHANGE 575 (2008); Willis, *supra* note 69; VALDES & MARCO, *supra* note 70. *Cf.* William S. Sicke, Jay R. Lund, & Josué Medellín-Azuara, *Climate Change Adaptations for California's San Francisco Bay Area Water Supplies*, 3 BRIT. J. ENV'T & CLIMATE CHANGE 292 (2013) (concluding with suggested changes to institutional design for water storage and delivery in the San

In sum, the prescriptions offered by engineering studies generally come down to: (1) change the existing institutional arrangements to look more like modeled arrangements without regard to how that change can or should take place; and/or (2) do more modeling. Nonetheless, as previously noted, models can be useful for planning for climate change impacts, as a basis for deliberation, and as a catalyst for changing institutional arrangements. But, just because there is a possible engineering solution if the legal and social parameters are hypothetically changed, it does not mean that the engineering solution can change the legal and social parameters in reality.

A. California and Optimization Model Research and Development

A premise of this paper is that optimization models of California's hydropower system are intended to be decision-support tools to assist with climate adaptation. To be fair, the intent behind developing optimization models, like any research product, is not singular.[88] There are usually multiple researchers, as well as funding agency staff, involved in developing a model. And each has an individual mix of motives—ranging from professional development, personal interest, political considerations, altruistic intents, and availability of resources. However, the published justifications of modelers for the studies, the statutorily-defined (and agency-interpreted) constraints on state funding, and the history of state agency involvement in oversight of and advice on optimization model research all tell a story of hope, that optimization models could be used to guide policy and dam operations in a way that incorporates or responds to changes in California's climate.

1. California Research Funding Constraints

For the past two decades, the state of California's support of research and development of optimization models has been contingent on that research being in the public interest and related to environmental protection.

Somewhat counterintuitively, the public funding for energy-related public interest research[89] came out of efforts to deregulate California's energy industries. In 1996, then-Governor Pete Wilson signed AB 1890, The Electric Utility Industry Restructuring Act.[90] The stated goal of the legislation was to "encourage

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Francisco Bay Area, although not focused on hydropower and without consideration to institutional feasibility of doing so).

88. *See, e.g.,* AMY POTEETE, MARCO JANSSEN & ELINOR OSTROM, WORKING TOGETHER: COLLECTIVE ACTION, THE COMMONS, AND MULTIPLE METHODS IN PRACTICE (2010).

89. This includes CALVIN and INFORM. *See* discussion *infra* Sections III(A)(2), III(B) Electric Utility Industry Restructuring Act, 1996 Cal. Stat. 4505, 4529 (codified as amended at CAL. PUB. UTIL. CODE § 330 (West 2017)) (introduced as A.B. 1890, 1996 Leg., Reg. Sess. (Cal. 1996)); CAL. ENERGY COMM'N, STRATEGIC PLAN FOR IMPLEMENTING THE RD&D PROVISIONS OF AB 1890 (1997), http://www.energy.ca.gov/reports/1997-06-01_500-97-007.PDF [https://perma.cc/SPD4-CNPD] [hereinafter CAL. ENERGY COMM'N, STRATEGIC PLAN FOR IMPLEMENTING THE RD&D PROVISIONS OF AB 1890].

90. 1 CAL. ENERGY COMM'N, FIVE-YEAR INVESTMENT PLAN, 2002 THROUGH 2006, FOR THE PUBLIC INTEREST ENERGY RESEARCH (PIER) PROGRAM REPORTING TO THE CALIFORNIA LEGISLATURE (2001), http://www.energy.ca.gov/reports/2001-03-02_600-01-004A.PDF [https://perma.cc/99AM-73TR].

innovation, efficiency, and better service from all market participants, and will [sic] permit the reduction of costly regulatory oversight."[91] But, the legislation also contemplated future research and development, as did a California Public Utilities Commission decision that informed AB 1890.[92] The Electric Industry Restructuring Policy Decision[93] considered that "in the transition to a more competitive environment" research and development in the public interest had the potential to be overlooked and unfunded. The Restructuring Act reflected this concern, requiring a surcharge on investor-owned utilities' retail sales to be directed to the California Energy Commission for public interest research and development activities that would likely be neglected by the competitive market.[94] To implement AB 1890, the Energy Commission created the Public Interest Energy Research program (PIER).

The mission of the program was to "conduct public interest energy research that seeks to improve the quality of life for California's citizens by providing environmentally sound, safe, reliable and affordable energy services and products."[95] Within their portfolio, the Energy Commission delineated four major research areas. Of these, the "environmental research focus area" was the most broadly defined. The Energy Commission's justification for environmental research was that "[w]henever energy is extracted, collected, transported, converted or utilized there are environmental impacts. The activities in these focus areas should be directed at better understanding and/or addressing the effects of those processes."[96] Although climate change is not directly addressed in the CEC's strategic plan for implementing AB 1890, as one Energy Commission staff close to the PIER program noted, "The reasoning behind PIER was that the energy sector was largely responsible for GHG emission and should therefore be responsible for funding solutions to the problems created by those emissions."

The scope of PIER was unprecedented in California, and led to the creation of the first, second, and third California Climate Assessments.[97] Optimization models figure heavily in each of these assessments. Two of the models in particular deal with adapting California's reservoir and hydropower systems to climate change. One of these is CALVIN, an economic-engineering optimization model of California's water system developed at the University of

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91. CAL. PUB. UTIL. CODE § 330(e) (West 2017); *see also* CAL. ENERGY COMM'N, STRATEGIC PLAN FOR IMPLEMENTING THE RD&D PROVISIONS OF AB 1890, *supra* note 89, at 1-1.

92. 1 CAL. ENERGY COMM'N, FIVE-YEAR INVESTMENT PLAN, 2002 THROUGH 2006, FOR THE PUBLIC INTEREST ENERGY RESEARCH (PIER) PROGRAM REPORTING TO THE CALIFORNIA LEGISLATURE 4 (2001)

93. D. 95-12-063, 64 CPUC2d 1 (1995).

94. CAL. PUB. UTIL. CODE §§ 381(a), (b) (West 2017).

95. CAL. ENERGY COMM'N, STRATEGIC PLAN FOR IMPLEMENTING THE RD&D PROVISIONS OF AB 1890, *supra* note 89, at 2–3.

96. *Id.*

97. PIER funding was extended in S.B. 1194, 2000 Leg., Reg. Sess. (Cal. 2000), and A.B. 995, 2000 Leg., Reg. Sess. (Cal. 2000), in 2000, but ended in 2012. Although research and development activities continue to be funded through the California Energy Commission, and those funds are from a surcharge on investor owned utilities, there are additional constraints to funding, which require in part that there be a direct benefit to IOU ratepayers. *See* S.B. 96, 2000 Leg., Reg. Sess. (Cal. 2000) (regarding EPIC funding).

California, Davis.[98] The other is INFORM, explicitly designed as a decision-support model to integrate short and longer-term forecasts into hydropower dam operation.[99]

2. Water and Energy Agency Advice and Oversight of Optimization Model Research and Development

Beyond providing research funding to develop optimization models as decision-support tools, state and federal agencies have provided oversight and, in some cases, played an influential role in deciding the parameters and variables included in models.

a. CALVIN

The underlying objective of CALVIN is to inventory, quantify, and compare water flows through reservoir operations to show the potential for the state's water system to respond under different operational constraints.[100] CALVIN was conceived as a way to provide potential solutions to California's complex and enduring water conflicts. In the words of the early modelers of CALVIN, the intent was to "provide[] an aid to placing local and other statewide planning efforts in context and giv[e] them greater focus" and to produce results that "have direct usefulness for policy, planning, finance, and operations planning problems regarding projected water scarcity at State, regional, and local levels."[101]

The impetus for the CALVIN project and for its continual development came from a more targeted goal. In the late 1990s, Doug Wheeler, then California's Secretary of Resources in the Wilson administration and former director of the Sierra Club, approached Henry Vaux, then University of California Associate Vice President for Programs, and researches at University of California Davis, about the possibility of conducting studies to assess opportunities for private sector investment in water infrastructure.[102] Knowing that the administration would come to an end before the funding and the project would, Howitt, an economist, and Lund, engineer, at UC Davis created a proof-of-concept optimization model of California's reservoir and conveyance system.[103]

98. *See, e.g.*, *University of California—Davis Statewide Economic-Engineering Water Model—CALVIN*, U.C. DAVIS CTR. FOR WATERSHED SCIS., https://watershed.ucdavis.edu/shed/lund/CALVIN/ (last visited Apr. 27, 2017).

99. *See, e.g., Integrated Forecast and Management (INFORM)*, HYDROLOGIC RESEARCH CTR., http://www.hrc-lab.org/projects/dsp_projectSubPage.php?subpage=inform (last visited Apr. 27, 2017).

100. *See University of California —Davis Statewide Economic-Engineering Water Model—CALVIN*, supra note 98.

101. JAY R. LUND ET AL., UNIV. OF CALIFORNIA-DAVIS, WATER MANAGEMENT LESSONS FOR CALIFORNIA FROM STATEWIDE HYDRO-ECONOMIC MODELING USING THE CALVIN MODEL (2009), https://watershed.ucdavis.edu/shed/lund/CALVIN/ProjectHandoutNew.pdf [https://perma.cc/8887-6X9Y].

102. Interview with Jay Lund & Josué Medellin-Azuara, University of California, Davis. Davis, California (June 5, 2016) (notes on file with author); RICHARD E. HOWITT ET AL., STATE OF CAL. RESOURCES AGENCY, INTEGRATED ECONOMIC-ENGINEERING ANALYSIS OF CALIFORNIA'S FUTURE WATER SUPPLY iii (1999).

103. *See generally* HOWITT ET AL., *supra* note 102.

From that point, CALFED,[104] California Natural Resources Agency (CNRA), and CEC have continued to fund CALVIN and provide researchers with oversight and advisory committees. CALFED was the first to take over funding for the CALVIN project and gave it an advisory committee. The committee included representation from the Metropolitan Water District of Southern California, Department of Water Resources, State Water Contractors, Kern County Water Agency, San Diego County Water Authority and the Environmental Defense Fund.[105] During the CALFED funding, CALVIN went from "a running model that produces numbers, but you don't believe them" to a "working model," in that it produced "reasonable results." [106] The main difference between the two in this case was detailed calibration, especially of hydrology.

Starting around 2003, the California Energy Commission began to fund research to improve the model and apply it to climate change planning. While there was no oversight committee, draft reports received comments from Energy Commission and California Department of Water Resources (DWR) staff along with outside researchers[107]—all experts in their fields. However, no hydropower or regional water managers provided comments.

In 2016, CALVIN research is still being funded by the California Natural Resources Agency, for a project on "Advancing Hydro-Economic Optimization to Identify Vulnerabilities, Tradeoffs, and Adaptation Opportunities in California's Water System" as part of the Fourth California Climate Assessment.[108] Additions to the model are also funded by a partnership between the U.S. Department of Energy, the Government of China, and the California Energy Commission[109] to investigate changes in hydropower operation on stream flow temperatures for aquatic habitat under multiple climate scenarios.

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104. CALFED was a collaboration between California and the Federal Government. *See* MARK LUBELL, ANDREA GERLAK & TANYA HEIKKILA, MAKING SPACE FOR THE RIVER 63 (Jeroen Frank Warner et al. eds., 2013); *see also* Giogos Kallis, Michael Kiparsky & Richard Norgaard, *Collaborative Governance and Adaptive Management: Lessons from California's CALFED Water Program*, 12 ENVTL. SCI. & POL'Y 631–643 (2009).

105. *See University of California—Davis Statewide Economic-Engineering Water Model—CALVIN*, *supra* note 98. Specifically the Advisory Committee included: "Anthony Saracino, Private Consultant (Chair); Fred Cannon, California Federal Bank; Duane Georgeson, Metropolitan Water District of Southern California; Jerry Gilbert, Private Consultant; Carl Hauge, California Department of Water Resources; Steve Macaulay, State Water Contractors and then California Department of Water Resources; Dennis O'Connor, California Research Bureau; Stu Pyle, Kern County Water Agency; Maureen Stapleton, San Diego County Water Authority; and David Yardas, Environmental Defense Fund" (acknowledgments page from 2009 description). *Id.* CALFED's investment was for approximate $450,000 and led to the publication of the 2001 CALVIN report.

106. Interview with Jay Lund & Josué Medellin-Azuara, *supra* note 102.

107. *See* JAY R. LUND ET AL., CLIMATE WARMING & CALIFORNIA'S WATER FUTURE (2003), https://calvin.ucdavis.edu/files/content/page/CECReport2003.pdf [https://perma.cc/D8F6-HARX].

108. At the time of writing, the research projects for California's Fourth Assessment are ongoing. *See Research and Tool Development*, CAL. NAT. RESOURCES AGENCY, http://resources.ca.gov/climate/safeguarding/research/ [https://perma.cc/8JEY-5W9J] (providing information on the research projects).

109. For more on the Department of Energy, China, and California Energy Commission research collaboration, *see* U.S./CHINA CLEAN ENERGY RESEARCH CENTER FOR WATER-ENERGY TECHNOLOGIES, cercwet.berkeley.edu (last visited Apr. 27, 2017).

b. INFORM

INFORM started with the goal of improving the operation of a particular facility, the reservoir and dam at Folsom[110]—a federal project and a key part of the Central Valley Project (CVP).[111] Researchers from Georgia Water Resource Institute along with the Hydrologic Research Center at San Diego (brothers Aris and Konstantine Georgakakos), developed a decision-support model to improve operations at Folsom for flood control, water delivery, and hydroelectric production.[112] The main purpose of the model was to demonstrate the gains that could be achieved for multiple objectives if short and long-term weather and climate forecasts were considered in reservoir management.[113] Later, the researchers added the goal of assisting decision-making in real time through integrating forecasts with an optimization model.[114] Although the initial design began with a single reservoir, through funding and guidance from multiple California and federal agencies, the scope of the model was expanded to incorporate the largest dams in Northern California and those associated with the CVP and California State Water Project.[115]

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110. Theresa M. Carpenter & Konstantine Georgakakos, *Assessment of Folsom Lake Response to Historical and Potential Future Climate Scenarios: 1 Forecasting* 249 J. OF HYDROLOGY 148 (2001); Huaming Yao & Aris Georgakakos, *Assessment of Folsom Lake Response to Historical and Potential Future Climate Scenarios: 2. Reservoir Management*, 249 J. OF HYDROLOGY 176 (2001); KONSTANTINE GEORGAKAKOS ET AL., HYDROLOGIC RESEARCH CTR. & GA. WATER RES. INST., INTEGRATED FORECAST AND RESERVOIR MANAGEMENT (INFORM), ENHANCEMENTS AND DEMONSTRATION RESULTS FOR NORTHERN CALIFORNIA (2008-2012)—FINAL PROJECT REPORT (2013), http://www.energy.ca.gov/publications/displayOneReport.php?pubNum=CEC-500-2014-019 [https://perma.cc/YY4B-7RM2]; GUIDO FRANCO ET AL., CAL. ENERGY COMM'N, CLIMATE CHANGE RESEARCH, DEVELOPMENT, AND DEMONSTRATION PLAN: CONSULTANT REPORT 35 (2003), http://www.energy.ca.gov/reports/2003-04-16_500-03-025FS.PDF [https://perma.cc/E53Q-LL5D] (The INFORM software is available for download from Georgia Water Resources Institute); *see Integrated Forecast and Reservoir Management (INFORM) for Northern California*, GA. WATER RESOURCES INST., http://www.gwri.gatech.edu/research/GWRI/INFORM [https://perma.cc/NM2X-XVVT] (last visited Apr. 8, 2017).

For additional information, see *Integrated Forecast and Management (INFORM)*, *supra* note 99; K.P. GEORGAKAKOS ET AL., HYDROLOGIC RESEARCH CTR. & GA. WATER RES. INST, CLIMATE CHANGE IMPLICATIONS FOR MANAGING NORTHERN CALIFORNIA WATER RESOURCES IN THE LATTER 21ST CENTURY: PIER FINAL PROJECT REPORT (2011), http://www.energy.ca.gov/2010publications/CEC-500-2010-051/CEC-500-2010-051.pdf [https://perma.cc/9GQA-KWSF].

111. The CVP is a massive infrastructure project that delivers water throughout California.

112. *See* Carpenter & Georgakakos, *supra* note 110, at 148; *see also* Yao & Georgakakos, *supra* note 110, at 176.

113. *See* Carpenter & Georgakakos, *supra* note 110, at 148–50; *see also* Yao & Georgakakos, *supra* note 110, at 176–78.

114. KONSTANTINE GEORGAKAKOS ET AL., INTEGRATED FORECAST AND RESERVOIR MANAGEMENT INFORM—A DEMONSTRATION FOR NORTHERN CALIFORNIA: PHASE 2 PROGRESS REPORT iii (2005), http://www.hrc-lab.org/projects/projectpdfs/INFORM_REPORTS/INFORM_phase1.pdf [https://perma.cc/Z46B-GRRH].

115. *See* INFORM CORE OFFICE, HYDROLOGIC RESEARCH CTR. & GA. WATER RES. INST., SUMMARY OF MEETING PROCEEDINGS: FIRST OVERSIGHT AND IMPLEMENTATION COMMITTEE MEETING (2003), http://www.hrc-lab.org/projects/projectpdfs/OICWEB/OIC_MEETING_PROCEEDINGS/SummaryMeetingProceedings_OIC-1.pdf [https://perma.cc/4GQA-ZQJK] [hereinafter FIRST OVERSIGHT AND IMPLEMENTATION COMMITTEE MEETING (2003)]; INFORM CORE OFFICE, HYDROLOGIC RESEARCH CTR. & GA. WATER RES. INST., SECOND OVERSIGHT AND IMPLEMENTATION

Originally, staff at the Department of Water Resources rejected the idea of funding further research to develop a regional model for integrating forecasts into reservoir management. According to PIER research managers at the time, it was assumed that water managers would not accept the results and the math underlying the model was "too complex."[116] After the funding plan was first rejected, the research manager from the Energy Commission set up a meeting between DWR representatives and a well-respected water policy non-profit in California, the Pacific Institute, in hopes that the staff there could provide some insight on the underlying math, and push for the project. At the meeting, although the math was still not clear to anyone besides Georgakakos, the Pacific Institute staff supported the project and convinced all state parties to provide financial support and oversight to develop the decision support tool.[117]

Funding for the project came from the PIER Program.[118] The California Natural Resources Agency approved funding for the project at $4 million per year and encouraged the researchers to be as expansive as possible in their approach.[119] The project was jointly funded by the National Oceanic and Atmospheric Agency (NOAA) as well. And it later received additional funding from CALFED.

From the outset, the funding agencies and researchers agreed that for the demonstration of INFORM to be successful in California, it would depend on close collaboration between the modelers and hydropower managers.[120] The importance of collaboration is expressed throughout the progress reports, summaries of meetings, and published peer-reviewed articles.[121] The second progress report for the INFORM project, for example, states that "[t]he fundamental premise of the INFORM project is that the use of short- and long-term operational forecasts in water management can only be achieved [if demonstration and assessment sites meet specific] conditions."[122] Half of these conditions rely on communication and co-production between researchers, stakeholders, and "end-users":

COMMITTEE MEETING (2004), http://www.hrc-lab.org/projects/projectpdfs/OICWEB/OIC_MEETING_PROCEEDINGS/SummaryMeetingProceedings_OIC-2.pdf [https://perma.cc/Q8ZF-Y7UU] [hereinafter SECOND OVERSIGHT AND IMPLEMENTATION COMMITTEE MEETING (2004)] ; INFORM CORE OFFICE, HYDROLOGIC RESEARCH CTR. & GA. WATER RES. INST., THIRD OVERSIGHT AND IMPLEMENTATION COMMITTEE MEETING OF THE INFORM PROJECT (2005), http://www.hrc-lab.org/projects/projectpdfs/OICWEB/OIC_MEETING_PROCEEDINGS/SummaryMeetingProceedings_OIC-3.pdf [https://perma.cc/5A2G-FH8U]; INFORM CORE OFFICE, HYDROLOGIC RESEARCH CTR. & GA. WATER RES. INST., FOURTH OVERSIGHT AND IMPLEMENTATION COMMITTEE MEETING OF THE INFORM PROJECT (2005), http://www.hrc-lab.org/projects/projectpdfs/OICWEB/OIC_MEETING_PROCEEDINGS/SummaryMeetingProceedings_OIC-4.pdf [https://perma.cc/E4WZ-UY5H] [hereinafter FOURTH OVERSIGHT AND IMPLEMENTATION COMMITTEE MEETING (2005)].

116. Interview with Guido Franco, California Energy Commission, Sacramento, CA. April 6, 2016 (on , file with author).

117. *Id.*; *see also* telephone interview with Konstantine Georgakakos, Hydrologic Research Center, Scripps Institute of Oceanography, San Diego, CA. December 6, 2016 (notes on file with author).

118. CAL. ENERGY COMM'N, STRATEGIC PLAN FOR IMPLEMENTING THE RD&D PROVISIONS OF AB 1890, *supra* note 89.

119. *Id.*; *see also* Interview with Guido Franco, *supra* note 116.

120. *See, e.g.,* KONSTANTINE GEORGAKAKOS ET AL., *supra* note 114, at 1–2.

121. *See id.*

122. *Id.* at 1-2

> (b) modelers, forecasters and managers have established a set of mutually-agreed-upon performance criteria to measure the effectiveness of decision policies;
> (c) a baseline quantitative system version is developed that reflects present management practices and operational models . . .
> (e) there is continuing participation of management staff in the demonstration activities and in user/modeler workshops for the mutual benefit of modelers, forecasters, and managers.[123]

To facilitate collaboration and communication, the three funding agencies—NOAA, CALFED and CEC—formed an "Oversight and Implementation Committee" (OIC) which included representation from CVP operations at the Bureau of Reclamation, forecasters from NOAA, and representation from California DWR in addition to the team of INFORM researchers from Georgia Water Resources Institute and Scripps Institute of Oceanography and the funding agencies.[124] The OIC facilitation allowed for greater familiarity with the project in management agencies and for data and system integration between INFORM and state and federal tools.[125]

Initially, the project managers and researchers expected that tailoring INFORM to California reservoirs would take about three to four years, after which the intent was to test its use for changed climatic conditions using climate scenarios rather than short-term forecasts and actual conditions. In practice, it would be over ten years before INFORM was adopted as a real-time decision support tool. Water managers wanted a side-by-side demonstration of INFORM, testing it against actual reservoir practices in real time with real inputs.[126]

B. How Do Hydropower Optimization Models Work?

The history of California agency oversight and funding of CALVIN and INFORM suggests that the models were developed with an eye toward informing and supporting decision-making and planning for California hydropower. The process of including variables and parameters in an optimization function allows the models produce hypothetical scenarios that can inform policy and operations. Each model, though, optimizes differently.

1. CALVIN

The chief architect of CALVIN, Jay Lund,[127] describes there being two key innovations of CALVIN: its database and its optimization solver. The database

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123. *Id.* at 1-2, 1-3.

124. SUMMARY OF MEETING PROCEEDINGS: FIRST OVERSIGHT AND IMPLEMENTATION COMMITTEE MEETING (2003), *supra* note 115; SECOND OVERSIGHT AND IMPLEMENTATION COMMITTEE MEETING (2004), *supra* note 115.

125. *See* ARIS P. GEOGAKAKOS, KONSTANTINE GEOGAKAKOS, N.E. GRAHAM, INTEGRATED FORECAST AND RESERVOIR MANAGEMENT (INFORM) FOR NORTHERN CALIFORNIA: SYSTEM DEVELOPMENT AND INITIAL DEMONSTRATION i (2007).

126. FOURTH OVERSIGHT AND IMPLEMENTATION COMMITTEE MEETING OF THE INFORM PROJECT (2005), *supra* note 115.

127. CALVIN has benefitted from the work multiple teams of engineers, economists, and generations of graduate students. There have been well over 20 engineering masters theses and PhD

innovation was to include metadata and contact information for all data entries. Including data provenance was a primary concern when Lund began to work on the CALVIN project. He had done prior work creating an optimization model for the Columbia River basin and was dismayed at the lack of reliability of data on water flows. He came to realize that if he were ever to work on a similar project for California, the data needed to be accessible and verifiable for the model outputs to be acceptable. The data and metadata are the main body of CALVIN.

While the Columbia River was the inspiration for CALVIN's body, another river, the Missouri, gave CALVIN its heart. The optimization solver, HEC-PRM. It is a computer program that retrieves data on water flows and animates the data by assigning values to flows throughout the reservoir system and "solving" the flows in a way that minimizes costs and maximizes gains for a particular goal. The end result is an "optimal" operations prescription, given the values assigned. The not-so-poetically-named HEC-PRM, or Hydrological Engineering Center's Prescriptive Reservoir Model, was designed to assist the Army Corps of Engineers in determining coordinated operating rules for a six-reservoir system along the main stem of the Missouri River. [128] A primary purpose of the solver is to determine "optimal" operating rules or a "plan" for reservoir systems where there are multiple conflicting objectives that need to be met.

> This plan [the output of the model] will identify the priorities to be assigned to conflicting objectives of operation. For example, the plan will determine whether water should be released from a reservoir if a demand exists for downstream flow for wildlife protection but a conflicting demand exists for continued storage of the water for recreation.[129]

The creators of HEC-PRM favored using weighted values to express social and environmental costs in the same terms as economic costs of operation in order to balance multiple objectives of operation and "permit display of trade-offs in operation for various purposes."[130] HEC-PRM's modeled reservoir system can only be constrained by a few input parameters. Of these, they tend to be physical constraints, for example, the outlet capacity of a reservoir. The user manual notes that "inviolable constraints on system operation are used frugally."[131] As

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dissertations on improvements to and new applications of the CALVIN model. Many of these students went on to work for the State Water Resources Control Board, the California Department of Water Resources, and utilities—notably the chief hydropower modeler for Pacific Gas and Electric. And, as noted earlier, it has had several advisory committees. But if any single person could be fairly pointed to as the primary architect and custodian of the model it would be Jay Lund, a professor of engineering at University of California at Davis. *See University of California—Davis Statewide Economic-Engineering Water Model—CALVIN*, U.C. DAVIS CTR. FOR WATERSHED SCIENCES, *supra* note 98.

128. INÊS C.L. FERREIRA & JAY R. LUND, U.S. ARMY CORPS ENG'RS, OPERATING RULES FROM HEC-PRM RESULTS FOR THE MISSOURI RIVER SYSTEM: DEVELOPMENT AND PRELIMINARY TESTING xi (1994), http://www.hec.usace.army.mil/publications/ProjectReports/PR-22.pdf [https://perma.cc/4X6W-FL4K].

129. BOB CARL, U.S. ARMY CORPS ENG'RS, HEC-PRM PRESCRIPTIVE RESERVOIR MODEL USER'S MANUAL: VERSION 1.0 9 (2003).

130. *Id.*

131. *Id.*

justification, the manual quotes two Rand Corporation economists, Hitch and McKean stating that "casually selected or arbitrary constraints can easily increase system costs or degrade system performance many fold, and lead to solutions that would be unacceptable to the person who set the constraints in the first place." [132] The design choice in HEC-PRM was to limit inviolable constraints and instead rely on value functions to impose operation limits; "[f]or example, instead of specifying maximum flow requirements for flood control, the system model should represent this objective through high costs of failure to maintain flows or storage levels below flood stage."[133] And so social and environmental considerations are weighted in economic terms too.

For the optimization solver to function, certain parameters and categories of variables need to be defined. First, the set of concerns between trade-offs needs to be defined and have decipherable values. Flood control in CALVIN, for example, is about how much water can be stored in a reservoir, not about where civic infrastructure is built.[134] There is a defined, and single, cost to decreasing environmental flows in a stream—not an array of costs based on who is carrying the burden from decreased flows. Second, from the beginning, in order for the trade-offs to be calculated, CALVIN depends on a centralized, coordinated system, which can immediately adjust to changes in preferences, without costs or delays from changing operating rules. In other words, in order to perform its optimization function, CALVIN needs to have a representation of a legal and political system that is quite unlike the one we have.

132. *Id.* at 9–10. It should be noted that the economists who the authors of the HEC-PRM model cite as the justification for the USACE design choice were neither discussing water allocation nor were they dead set against balancing choices not expressed in commensurable terms. The quote comes from a Rand Corporation report, the purpose of which was to demonstrate the usefulness of applying economic thinking—defined in the report as "trying to make the most efficient use of the resources available"—to military problems in the nuclear age. *See* C.J. HITCH & R. MCKEAN, THE ECONOMICS OF DEFENSE IN THE NUCLEAR AGE v (1960) In the section that USACE quotes from, Hitch and McKean were presenting what to do about "incommensurables"—i.e., gains and costs that cannot be expressed in a "generally acceptable" common unit, for example the value of human life, *id.* at 183–87, or the "the diplomatic trouble and risks involved in various overseas countries [in planning bombing attacks.]" *Id.* at 186. They argue that when the policy analysis exercise is to compare two or more options, at least one of which has an incommensurable element, it is "far preferable" to put some kind of monetary valuation on the incommensurable element for comparison's sake rather than "placing limiting constraints on the solution" [the example they provide is "rul[ing] out all solutions in which casualty rates exceed a certain arbitrary percentage" or "declaring certain countries off-bounds [for overseas basing.]" *Id.* at 186. But, even still, Hitch and McKean state that "[s]ome [] constraints on an analysis are necessary and justified" and that is valuation of incommensurables is "not very useful" if "all the leading alternatives involve significant and different incommensurables." *Id.* at 186 n.6. The two economists go on to outline additional analysis options that may be preferable to trying to assign numerical value to objectives that are by their nature incommensurable with quantification. For example, "In some cases where systems achieve incommensurable objectives, the analyst may be able to design another system which is better at achieving some things and as good, or almost as good, at achieving the others. . . . In many cases the analyst's ingenuity may be more rewardingly exercised in trying to find ways of satisfying multiple objectives than in devising common measures for them. It can be argued that the *chief* gain from systemic analysis is the stimulus that it provides for the invention of better systems." *Id.* at 187.

133. CARL, U.S. ARMY CORPS ENG'RS, *supra* note 129, at 10.

134. *Cf.* GILBERT F. WHITE, CHOICE OF ADJUSTMENT TO FLOODS (1964).

2. INFORM

INFORM, as with its predecessor model focused on Folsom operations, was designed to support decision-making at multiple timescales.[135] The short- and midrange model is designed with an hourly resolution and a duration of one month.[136] The long-range model has a monthly resolution with a horizon of one year. Each timescale has different management objectives.[137] Short term objectives focus on maximizing daily energy generation, and/or maximizing the value of daily energy, considering minimum flow requirements, energy prices ("as a function of power demand"), and the times that a given hydropower plant is committed to operate at capacity ("dependable capacity commitments"). [138] The long- and mid-range decision model is designed to "determine reservoir release and level sequences that satisfy Folsom's long-term objectives—flood control, hydropower generation, water supply, environmental protection, and drought management." [139]

Between each model run timescale, and with the support of the modeled results, the INFORM designers anticipate specific kinds of decision-making in a particular sequence. The long-range model is designed to run first, to support deliberations between the planning departments of hydropower management agencies to make "key decisions" on "water supply contracts, reservoir releases, energy generation, and reservoir coordination strategies."[140] Output from the short- and midrange models are intended for operational decisions (e.g., power plant scheduling, water supply and flood management), and so are intended to support the "operational departments" of management agencies. [141] And the results of the hourly time resolution model for turbine dispatch are intended to be used for "near real time operations."[142] Each of the layers is designed so that outputs of one informs the others. [143]

Like CALVIN, INFORM depends on weighting performance metrics to signify levels of importance among reservoir objectives.[144] The highest weight is imposed on parameters in order to find sequences that first meet the pool level constraints of reservoirs and avoid flood damage. An intermediate weight is assigned to limit those sequences to ones that maintain "high feasible reservoir

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135. Yao & Georgakakos, *supra* note 110, at 183.

> The Folsom decision module is designed to support reservoir management decisions pertaining to multiple time scales. Specifically, this module consists of (a) a long/mid-range control model with a horizon of 60 days and daily time steps, (b) a short-range control model with a horizon of one day and hourly time steps, and (v) a turbine commitment and load dispatching model pertaining to each hour.

Id.

136. GEORGAKAKOS ET AL., *supra* note 114, at 4-3.

137. Yao & Georgakakos, *supra* note 110, at 185–97; KONSTANTINE GEORGAKAKOS ET AL., *supra* note 114, at 4-4.

138. Yao & Georgakakos, *supra* note 110, at 185.

139. *Id.* at 186. *See* GEORGAKAKOS ET AL., *supra* note 114, at 4-4.

140. *Id.*

141. *Id.*

142. *Id.*

143. *Id.* at 4-5

144. Yao & Georgakakos, *supra* note 110, at 187–88 (discussing penalty parameters).

levels."[145] From there, a minimal weight is assigned to select those that "additionally optimize power efficiency."[146] The "optimal" choices are found using the "Extended Linear Quadratic Guassian" or ELQG, also developed by Aris Georgakakos and H Yao.[147] The exception to this design lies with the treatment of minimum environmental flows. "The minimum release [from reservoirs] . . . is set to 100 cfs [cubic feet per second] to accommodate downstream environmental and water supply requirements."[148] Model *users*, though, determine the acceptable amount of water in reservoirs, and the risk from exceeding limits defined from rule curves.[149]

The result of the weighting and strict rules for minimum flows in INFORM roughly matches legal considerations. Minimum environmental flows are a strict requirement, and flood control is weighted more heavily than hydropower generation or water storage.

Although individual laws for hydropower operation are not mentioned in the OIC meeting summaries, there are several instances in which researchers depended on representatives, from federal and state hydropower reservoir managing agencies, to determine parameters for the INFORM model. For example, lead researchers (co-Principal Investigators, or co-PIs) were required to work with the Committee's contacts at DWR and the Bureau of Reclamation to "define the link between the Bay Area management objectives with the objectives of the INFORM reservoirs."[150] In this way, the OIC may have provided a mechanism for coherence between the rules and laws that form the context for the work managers and operators and the parameters that constrain the algorithm in INFORM.

Even with positive, believable results, and inclusion of stakeholders, and even though the DWR wanted to fund the actual use of INFORM, the department was unable to allocate money to the project until several years into the recent drought (2015), well over a decade since INFORM was first funded by California. Still, DWR is tailoring the model for just one river system and only for state (and not federally) controlled dams, at that; only one of the dams in this system has a hydroelectric generation facility, and the tailoring and implementation process is still expected to take two additional years before it is operational.[151]

It is important to note that although CALVIN and INFORM are both optimization models, they are very different types of decision-support tools. The "time-steps" for CALVIN are monthly and seasonal—coarser than INFORM's nested hourly, daily, monthly, and seasonal time-steps. The choice of time-step relates to the types of decisions both models are intended to influence. CALVIN is

145. *Id.* at 188

146. *Id.*

147. *See generally* Aris P. Georgakakos, Huaming Yao, & Yongqing Yu, *A Control Model for Dependable Hydropower Capacity Optimization*, 33 WATER RESOURCES RESEARCH 2349 (1997).

148. Yao & Georgakakos, *supra* note 110, at 187.

149. *Id.*

150. SUMMARY OF MEETING PROCEEDINGS: FIRST OVERSIGHT AND IMPLEMENTATION COMMITTEE MEETING (2003), *supra* note 115, at 5.

151. Personal communication with M. Anderson, Department of Water Resources, April 2016 (on file with author).

intended for large-scale investments and planning[152] whereas INFORM is intended to support daily operations of hydropower dams in addition to longer-term planning. Finally, how the two models treat the task of optimization is different. CALVIN looks at the system of reservoirs across multiple rivers and trades objectives throughout. INFORM looks at individual reservoirs, in addition to larger reservoir networks, and trades uncertainty across objectives over time. Both models "work" in that they produce outcomes that are optimized for the conditions set in the models. They determine operational rules that produce more electricity, more environmental flows, and still manage to reliably store more water while improving flood prevention, all on the virtual rivers[153] represented in the models. But the translation from rules developed for the virtual river back into reality does not occur on a 1:1 basis.

IV. INSTITUTIONAL ECONOMICS CRITIQUE APPLIED TO CALVIN/INFORM

The relationships among law, history, and values are important to models precisely because the models do not recognize them—making the models' weighted trade-offs between uses in the models suspect. INFORM and CALVIN both attempt to model a system that is governed by inconsistent sets of laws that change from dam to dam and make the system clear enough so that they can calculate which allocations of water are optimal across the system. This is not an easy task, but in simplifying or ignoring the institutional arrangements that govern hydropower dams in California, the modelers swapped one set of institutional arrangements (heterogenous and slow moving with the potential for conflict and conflict resolution) for another (centralized, coordinated, without admission of the existence of conflicts, let alone their resolution). Each of these systems, the one we live with and the ones in CALVIN and INFORM, will produce different values—and take different values into account to begin with.

One could argue that value is included in optimization models through the use of the Lagrange multiplier (CALVIN), or penalty parameters (INFORM), or the inclusion of inviolable minimum streamflows in models—all of which serve to designate the relative importance of multiple objectives of reservoir management, in theory, similar to how law designates relative importance.

But, even if the use of penalty parameters and Lagrange multipliers were a reflection of value, it is still a distorted reflection. The quantitative weighting of values employed in optimization models creates a different sort of balancing than the qualitative assessments of value used in political and legal processes.[154] Qualitative assessments are necessary for conflict resolution because values can

152. *See supra* discussion in Part I. *See also* interview with Jay Lund & Josué Medellin-Azuara, *supra* note 102.

153. WHITE, *supra* note 15.

154. For more on the problems of substituting quantitative reasoning for qualitative processes to resolve conflicts through allocation, see Bauer, *Slippery Property Rights*, *supra* note 11, at 109–155 ("Resolving conflicts requires qualitative measures of value and a qualitative logic, to weigh and choose among a web of rights, rules, purposes, and interests. This again is an inherently judicial and political task, for which private bargaining and exchange cannot substitute. The same is true of internalizing externalities.").

conflict and evolve.[155] This is evident in the history of hydropower governance, among other places. Over the past several decades, for example, there has been more emphasis placed on environmental protection and instream flows as well as coordination between agencies.[156] Quantitative valuation, though, depends on static values, which are assigned in a way that negates the possibility of conflict within models.

Additionally, the parameters that define how the quantitative values in models like CALVIN and INFORM operate, and allow them to operate, are extremely different from *procedural rules* in reality. Modelers for INFORM and CALVIN created virtual hydropower systems that are centrally controlled, and in which coordination between reservoirs is assumed to be possible and instantaneous. In contrast, the process for changing parameters to reallocate water across the virtual systems is near instantaneous. The process for changing institutional arrangements in actual hydropower system is varied depending on dam type, location, and historical context. Changing the rules for a FERC license, for example, depends on the specifics of that license, like whether the license has a reopener clause or is up for renewal, and so forth. Changing the flood control rule curves of a dam depends on the willingness and financial means of the Army Corps of Engineers to undertake a study to rewrite the rules and comply with NEPA.

V. WHAT NOW? POTENTIAL RESEARCH AND NEXT STEPS FOR INCLUDING LEGAL CONTEXT INTO OPTIMIZATION MODELS

Optimization models are playgrounds in which users can experiment with different policy and operation scenarios. The playground, and all the toys and structures in it, have been arranged *just so*. The trouble with the "just so-ness" of the grounds is that it is arranged in line with the preferences of engineers, not the preferences or concerns of decision-makers. So, how can the playground be redesigned to encourage decision-makers to play? How can optimization models be re-worked to include socio-legal context?

It should be noted, that there is no shortage of resistance to the idea of including law and politics in optimization models. Carl Bauer, a political economist, once asked Lund about whether CALVIN incorporated politics. Lund replied that it didn't, because if it did, "the model wouldn't work."[157] In conducting background research for this paper, the engineers and economists I spoke with regularly noted their strong belief that the "problem" was with policy people, not with the models.

Engineers are trained in engineering, not history, law, or politics. It would be unfair and unreasonable to expect modelers to be something they are not trained to be. But would it be fair and reasonable to re-think how engineers are taught and

155. *See* DEBORAH STONE, POLICY PARADOX (2002). *See also* Wandschneider, *supra* note 11, at 94 ("Property institutions inevitably and simultaneously establish the framework for the (efficient) allocation of resources and determine the distribution of access and control over resources (citations omitted). Therefore, in the institutionalist view, institutional questions inevitably involve conflict.")

156. *See supra* discussion Parts II.B, II.C (discussing amendments to FPA).

157. Phone interview with Carl J. Bauer, University of Arizona, School of Geography and Development, August 26,2016 (notes on file with author).

what they are taught? Could broader inclusion of social science and humanities help engineers think through how their products fit into social settings?

Even if engineers were trained to think through social context more thoroughly, could models capture even just formal law sufficiently? The network of laws that govern hydropower in California is evolving, complex, and multiple (as discussed above in Part II). Those characteristics would be difficult to integrate into models in which all dams are treated as equivalent—a design choice made to simplify programming and minimize computer model run time. Could including lessons from the development of artificial intelligence be incorporated into decision-making tools for resources? What is gained or lost by using computer code as the lexicon for balancing multiple objectives and values? Can code legitimately function as the language of dispute resolution?

What about less direct methods of shaping optimization models? Can close collaboration and coproduction of models with individuals who are intimately aware of how the legal constraints and connections work on the ground—whether managers or operators—allow for a way to include preferences and values specific to the time of their creation?

The history of the development of INFORM may provide an example of this type of coproduction. INFORM had a very active oversight committee in which the managers of the existing real systems helped to shape choices in model design. That collaboration between the designers and practitioners, who must work within the world of politics and conflict, may have provided a way to include that context in the model, even if not directly, and make it more likely to be adopted. Even still, the history of INFORM suggests that coproduction is not a guarantee for success, or at least immediate success. It took an extreme event (prolonged drought) before the Department of Water Resources could fund even partial implementation of INFORM. Future research should be done to investigate the potential for coproduction, or transdisciplinarity, to overcome the gaps between the virtual reality of optimization tools and the world in which decisions are actually made.