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U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
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Abstract

While models to value ecosystem services exist, they suffer from a lack of "portability" in the sense that a single modelling framework developed for one site cannot be imported and applied to another. Additionally, benefit estimations are often fragmented, incomplete, incomparable, and in heterogenous metrics, thus preventing aggregation to arrive at one comprehensive value. In the context of hydropower, the methods, as well as the metrics used to value the associated ecosystem services, vary between stakeholders (e.g., competing water users, agencies, etc.), detracting from the ability to assess the total value of a hydropower project and/or water management schemes, or compare value between competing water users. Further, current methods to value water neglect non-market ecosystem services' values by failing to account for externalities, resulting in misallocation of costs (e.g., obligatory stakeholder payments for water use) and misinterpretation of hydropower benefits. The benefit-cost ratios in hydropower development are often incomplete because non-market benefits are excluded (e.g., benefits, such as fish habitat resiliency and agricultural water reliability, derived from hydropower development). An approach to enable consistent, standardized hydropower benefit-cost analyses does not currently exist. This paper conceptualizes a methodology to standardize ecosystem services valuation in the context of hydropower projects through the integration of the U.S. Environmental Protection Agency's existing Final Ecosystem Goods and Services Classification System framework and economic valuation techniques and demonstrates the applicability of this methodology through a limited proof-of-concept application (the New Waddell Plant, a pumped hydroelectric energy storage facility in Phoenix, AZ). The beauty of our proposed framework lies in its ability to be imported and applied to any other pumped storage facility after accounting for site-specific features.

Keywords

Ecosystem services, valuation framework, benefits transfer

Section 1: Introduction

The inadequacy of traditional institutional frameworks to price ecosystem services puts such systems and their services at risk. (Markandya et al., 2014, Liekens et al., 2013). Because ecosystem services are not adequately captured in commercial markets or quantified in value terms, they are given too little weight in policy decisions and can result in negative implications, such as a lack of a cost-accurate policy instrument for restoration and management of natural systems (Markandya et al., 2014, Liekens et al., 2013). The absence of accurate valuations of ecosystem and their services limits an accurate environmental impact assessment and limits the scope of policy instruments to rectify the situation.

Debates surrounding the methodology for the valuation of ecosystem services date back to a seminal work attributed to Robert Costanza (1997). Referred to as the Costanza debate, this paper compiled massive data sets on land cover and valuation studies to arrive at a total value for Earth's ecosystem services (Robertson, 2011). They described the Earth as a "highly efficient, least cost provider of human life support services," and (in 1997 dollars) valued it somewhere between $16 and $54 trillion, with a median value of $33 trillion. This paper became central to policy and academic discussions on the appropriate methodology and scope of ecosystem service valuation studies. The controversial figure of $33 trillion was critiqued as "a serious underestimate of infinity" (Robertson, 2011) with no clear, real-world application since the number far exceeded the global gross domestic product in 1997. This caused critics to argue that valuation should consider only marginal changes from current conditions represented by actual, achievable transactions in the real-world (Robertson, 2011). Among other things, the work highlighted the definitional limits of trade in ecosystem services. More specifically, that it is illogical to speak of making trades to a degree that the foundation of life itself is threatened (Robertson, 2011), implying that there is a limit to the number of ecosystem services that can be traded away by a person or a country. These realizations called for the National Research Council to deem that *valuation of services should be conducted on a small scale* (Robertson, 2011); the entirety of a given service or set of services present in ecosystems is far more difficult, if not impossible, to price using conventional valuation methods.

Monetary valuation, the most conventional method of valuation, not only provides quantitative estimates of the consequence of (societal) action (Liekens et al., 2013) but also provides a basis to communicate value to various stakeholders using a commonly understood metric (money). Reliance on a common metric to value these services enables stakeholders to undertake informed trade-offs (using a cost-benefit analysis framework) to assess the impact of marginal changes in the provision of an ecosystem service relative to the provision of the same service in an alternative scenario (Liekens et al., 2013). It is to be noted, however, that monetary valuation of ecosystem services comes with its own set of risks (Liekens et al., 2013). One such risk arises from the neglect of ecosystem services or components whose importance is not straightforward or explicit in monetary terms (Liekens et al., 2013). This problem may lead to the "risk that the valuations of ecosystem services assessment would be limited to those services that would have a material risk for the investor" (Liekens et al., 2013). Additionally, assigning a price tag to natural elements gives rise to a "license to pollute" (or to destroy) (Liekens et al., 2013).

Further, monetary evaluation also involves certain methodological limitations. For instance, it risks undervaluing the importance of specific ecosystem elements not because of a lack of importance, but because its importance cannot be quantified in monetary terms (Liekens et al., 2013). For instance, quantification of ecosystem services runs the danger of "involving trade-offs with biodiversity" (Proenca et al., 2015). While the risk of taking recourse to monetary valuation is a general concern, there are other concerns as well, such as operational concerns (Proenca et al., 2015)., While it may seem worthwhile to invest in systems that divert a part of the benefits away from society and to the stakeholders (as compensation for foregone efforts and income), it gives rise to operational concerns involving compensation; for instance, who should be the beneficiaries of this payment, how should the costs be divided, etc. (Proenca et al., 2015).

Despite the risks of monetary valuation, however, its usefulness cannot be dismissed; much depends on how it is applied and in what contexts. Further, it may also depend on how monetary valuation methods are used relative to other valuation or assessment methods, and it should ideally be a part of a broader assessment, like multi-criteria analysis (Proenca et al., 2015).

, *Benefits transfer*, a valuation technique, that makes use of existing knowledge rather than empirical research to inform decisions has been steadily gaining steam (Brouwer et al., 2005). Benefits transfer relies on the use of existing nonmarket valuation studies from various study sites and applies them to a previously unstudied site (Bateman et al., 2002 (1); Bateman et al., 2002 (2); Champ et al., 2003; Freeman, 2003, Alves et al., 2009). This technique involves two different types of transfers. The first, value transfer can be a single-point estimate transfer, an average value (or measure of central tendency) transfer, or an agreed-upon estimate transfer. The second, function transfer, can be either a demand function transfer or a meta-analysis regression benefit function transfer. Benefit transfer comes with its own set of pros and cons. This method is the least costly (both in terms of time and resources) alternative to conducting an original valuation study. In fact, it is often used as a screening technique to determine if a more detailed original valuation study needs to be conducted. Under the assumption that consumers' preferences for environmental goods are similar and stable across the decision context and monetary valuation is considered a valid basis for decision making, benefits transfer is the most *efficient* approach in terms of time and resources. In fact, the more similar the sites, the more accurate will be the estimates. Having said that, it also comes with its share of limitations. For one, there are limitations on the extent to which these estimates are transferable across societies with differing preferences, constraints, and institutions (Bateman et al., 2009; Champ et al., 2003). Additionally, the inability to allow for characteristics to change over space and time, the inability to measure new impacts as measures are based on previous studies (Turner et al., 1999, and existence of substantial transfer errors (Brouwer, 1999; Bateman et al., 2009, Bateman et al., 2011) are some of the other limitations to using these techniques. To reiterate, its limitations notwithstanding, this is the most convenient and least costly approach to valuation of ecosystem services.

Other factors affecting the valuation of ecosystem services involve uncertainty stemming from a lack of understanding of factors explaining the variability in the delivery of goods and services by ecosystems (Dendoncker, et al., 2013).

Classification of ecosystem services also has a role to play in their valuation. While the current classification of ecosystem services is one that is largely accepted (provisioning services, regulating services, cultural services, and supporting services) (Proenca et al., 2015), there are several caveats regarding its use in valuation exercises. For instance, without careful accounting, supporting services present a risk of double counting by identifying overlapping services. To overcome this limitation, recent classifications have entirely dropped *supporting services* (as a separate category) and instead treat them as ecosystem processes that underpin final ecosystem services.[1]

Crop production, for instance, is a final ecosystem service that is heavily dependent on other processes like soil formation and habitat provision for pollinators. From a valuation perspective, crop production is the final ecosystem service and other inputs to the process, like access to benefits or goods (e.g., apples), requires other capital inputs beyond natural capital, such as human capital for instance (Proenca et al., 2015). This points to a system-based approach to the valuation of ecosystem services.

"The Economics of Ecosystems and Biodiversity for Agriculture and Food" (TEEBAgriFood[2]) is one of the most comprehensive, system-based approaches used by the United Nations Environment Program to capture and price the synergies between the eco-agri-food systems in a bid to avoid the risks and limitations inherent in the adoption of simplistic metrics like "per hectare productivity" to value agricultural performance. Instituted in 2018, this program overcomes the limitations of a conventional "production only" approach limited to the production segments of food value chains and to those stocks, flows, outcomes, and impacts observable in markets, and hence reflected in standard economic statistics. This approach looks along entire food value

[1] Final ecosystem services correspond to the outcomes from ecosystems that are enjoyed by people.

[2] http://teebweb.org/our-work/agrifood/

chains to reveal significant but economically invisible (i.e., non-market) stocks and flows that need to be considered and priced into the system.

In this paper we will use a system-based, site-specific, benefit transfer approach for the valuation of ecosystem goods and services associated with hydropower production. Hydropower development and operation are often contentious because of the potential for the environmental impacts they may cause. While the environmental impacts of hydropower operations are often assessed, an economic value is seldom assigned to those impacts, whether positive or negative. Further, benefits created by hydropower (e.g., reliability in provisioning of water for agricultural and municipal use, transportation, recreation, habitat, etc.) are currently not economically valued in analyses for permitting and developing new hydropower. A well-designed payment scheme for ecosystem services in this context would require an understanding of the following: (1) the type of ecosystem services provided by the hydropower facility and (2) the distribution of these services among the various stakeholders (Vogl et al., 2015). While many studies have valued a single specific service associated with hydropower production, very few have attempted to value all its amenities and impacts. This study is the first to provide a comprehensive framework categorizing all associated ecosystem services, as well as map those services to the relevant stakeholder—the end goal of this exercise is to develop a metric that can be harmonized across stakeholders to price these services. The starting point of our mapping exercise is the Final Ecosystem Goods and Services Classification System (FEGS-CS)[1] (Landers, et

[1] https://cfpub.epa.gov/si/si_public_record_Report.cfm?Lab=NHEERL&dirEntryId=257922

al., 2013) system developed by the U.S. Environmental Protection Agency (EPA). This is applied to a pumped hydroelectric energy storage (PHES) facility in Phoenix, AZ (New Waddell Plant). The rest of the paper is organized as follows. Section 2 lays out the starting point of this mapping exercise and our approach to perform it. Section 3 lists out the materials and methods used in this analysis. Section 4 lays out the results of this analysis. Section 5 discusses the findings and Section 6 concludes.

Section 2: Stakeholder Matrix

The FEGS-CS system developed by the EPA is the starting point of our analysis. We use this in conjunction with a comprehensive list derived from (Yang and Jackson 2011, Prasad, Jain et al. 2013, Saulsbury 2020), and then map the merged lists to the relevant stakeholders. Table 1 below is a sample of ecosystem services for both above and below ground reservoir PHES plants. It shows a small sample of some of the ecosystem services and the corresponding FEGS-CS codes. A more comprehensive list considering a larger number of ecosystem services that ought to be considered when valuing PHES is included in the Appendix.

○ TABLE 1: SAMPLE OF ECOSYSTEM SERVICES AND IMPACTS FOR PHES PROJECTS[1].

Environmental Subclass	Benefit type	Benefit Description	FEGS-CS code
Aquatic	Surface water quantity	Surface water supply	11.0101 11.0102 11.0103 11.0104 11.0205 11.0301 11.0302 11.0303

[1] This is a small sub sample of the table. The full table is available in the appendix.

			11.0304 11.0304 11.0401 11.0402 11.0501 11.0502 11.0503
Terrestrial	Recreation	Recreational access for camping, hiking, etc.	11.0605 21.0605
Aquatic	Aquatic ecology	Migration delays	11.0201 11.0207

This table combines information from the environmental engineering literature identifying many environmental impacts of the construction and operation of plants, the environmental economics literature identifying benefits, such as recreation, and recent work by the EPA to create the FEGS-CS system that maps ecosystem services to their respective beneficiaries (Landers and Nahlik 2013).

Entries in this table may be interpreted as follows: the first two digits of the FEGS-CS before the period identify the environmental subclass, and the digits after represent the stakeholder. For instance, 11 represents streams and rivers, while 21 represents forest land. The digits after the period represent the stakeholder, with the first two describing a broad category and the second two digits describing a more detailed subclass.

To understand how this classification system works, consider the following FEGS-CS code 11.0101. The 11 before the period describes benefits from rivers and streams. The first 01 after the period identifies an agricultural beneficiary and the second 01 describes the subclass of irrigators. The code 11.0103 describes the same rivers and streams with an agricultural beneficiary, for the subclass of livestock owners using the water to enhance grazing. The table shows many potential beneficiaries who may use surface water, including agricultural, municipal, industrial, and commercial water users.

Recreation beneficiaries are listed as benefitting people who engage in respective recreational activity. This service in particular highlights the fact that services can both be gained and lost from the operation of a PHES plant. For instance, some plants, such as the New Waddell Plant examined in the case study, create recreational opportunities where none previously existed, while other PHES plants often end up reducing the quantity or quality of recreational activities (Kotchen et al 2006, Wang et al 2010, Getzner 2015).

The final column in the table illustrates mapping to a stakeholder—this is the most critical component when performing a tradeoff analysis. “The ability of salmon to migrate” is a significant ecosystem service that can be lost when hydropower plants are constructed. It is not possible to quantify the associated cost in monetary terms, implying the absence of a common metric for the value of this service across all the different stakeholders. Commercial and subsistence fishers, as well as individuals concerned with preservation of salmon will be affected and their willingness to pay to ensure the migration is allowed functions as the common metric. An analysis of the costs and benefits of the hydropower project would be incomplete unless these are accounted for and mapping the ecosystem service to stakeholders ensures that all costs and benefits are accounted for, but not counted more than once.

These ecosystem services and the beneficiaries can also be visualized. Figure 1 includes ecosystem services, their linkages to the relevant stakeholders in the right column, and their linkages to the “four capitals” used to represent society’s ability to accumulate assets over the long term.

FIGURE 1: FLOW DIAGRAM FROM EXTERNALITIES TO STAKEHOLDERS[1].

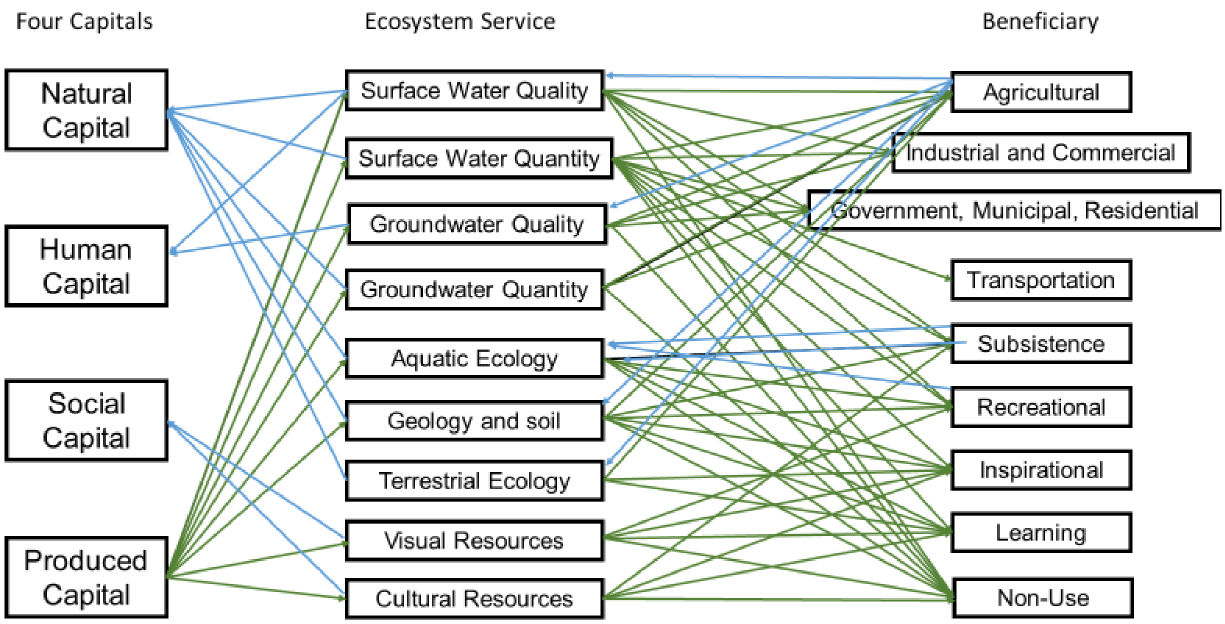

Table 2 includes a brief description of the information in Table 1 to allow for easier readability. This shows a list of beneficiaries and maps them to the environmental subclass that is as complete as possible for any possible PHES. This can be tailored easily to a specific example. A plant using underground storage for instance, can use the groundwater subclass, whereas a plant using above ground storage can use lakes and ponds for the reservoir that is created.

Any study valuing a PHES project can look at this table and examine all possible stakeholders and environmental subclasses that may be affected. For any specific case, the benefit list can be narrowed based on whether the project will affect local agriculture, recreation, water quality, aquatic ecosystems, and more.

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[1] Green arrows indicate rightward flows and blue arrow represent leftward flows.

TABLE 2: STAKEHOLDER MATRIX[1].

		Environmental Subclasses				
Beneficiary Category	Beneficiary Description	Rivers and Streams	Ground Water	Forests	Agroecosystems	Lakes and Ponds
		XY=11	XY=16	XY=21	XY=22	XY=13
XY.01 Agricultural						
XY.0101	Irrigators	X	X		X	X
XY.0102	Concentrated Animal Feeding Operators (CAFO)	X	X			
XY.0103	Livestock Grazers	X	X			
XY.0104	Agricultural Processors	X	X			X
XY.0105	Aquaculturists	X	X			X
XY.0106	Farmers				X	
XY.0107	Foresters	X	X			X
XY.02 Commercial/Industrial						
XY.0201	Food Extractors	X		X		
XY.0202	Timber, Fiber, and Ornamental Extractors			X		
XY.0203	Industrial Processors	X	X			
XY.0204	Industrial Dischargers	X	X			
XY.0205	Electric and Other Energy Generators	X				
XY.0206	Resource-Dependent Businesses			X		
XY.0207	Pharmaceutical and Food Supplement Suppliers	X	X	X		

[1] This table shows possible combinations of environmental subclass and the potential beneficiaries. This translates Table 1 into a matrix that shows the stakeholders directly. This table is comprehensive to any project.

XY.0208	Fur / Hide Trappers and Hunters	X		X		
XY.03 Government, Municipal, and Residential						
XY.0301	Municipal Drinking Water Plant Operators	X	X			
XY.0302	Wastewater Treatment Plant Operators	X				
XY.0303	Residential Property Owners	X	X	X		
XY.0304	Military / Coast Guard	X		X		
XY.04 Commercial/Military Transportation						
XY.0401	Transporters of Goods	X				
XY.0402	Transporters of People	X				
XY.05 Subsistence						
XY.0501	Water Subsisters	X	X			
XY.0502	Food Subsisters	X		X		
XY.0503	Timber, Fiber, and Fur	X		X		
XY.06 Recreation						
XY.0601	Experience and Viewers	X	X	X		X
XY.0602	Food Pickers and Gatherers	X		X		X
XY.0603	Hunters	X		X		
XY.0604	Anglers	X				X
XY.0605	Waders, Swimmers, and Divers	X	X			X
XY.0606	Boaters	X	X			X
XY.07 Inspirational						
XY.0701	Spiritual and Ceremonial	X		X		

XY.0702	Artists	X		X		
XY.08 Learning						
XY.0801	Educators and Students	X	X	X		
XY.0802	Researchers	X	X	X		
XY.09 Non-Use						
XY.0901	People Who Care (Existence)	X	X	X		
XY.0902	People Who Care (Option/Bequest)	X	X	X		

We are now going to demonstrate how we use this matrix to value a specific PHES plant, the New Waddell Plant. The New Waddell Plant is situated in Central Arizona, about 45 miles north of Phoenix. The power plant is part of the Central Arizona Project that diverts water from the Colorado River on the western border of Arizona. In addition to PHES, the water is used for industry, agriculture, and municipalities. The project also supplies benefits from flood control and recreation (Barnes, 1992). The dam is on the Aqua Fria River that flows into the Gila River, and ultimately back to the Colorado River.

The New Waddell Dam was chosen as the case study for this project on account of the varied publicly available data on this site. Ideally, a site-specific primary survey to record benefit and cost numbers would have been the best data source to demonstrate the efficacy of our methodology. In the absence of any such primary surveys, we took recourse to the next best available option—publicly available data—to demonstrate the efficacy of our suggested framework. Of all the sites that we had shortlisted for demonstration purposes, the New Waddell Dam conducts surveys on local recreational use by type of activity and publicly disseminates the results, making it the most exhaustive list of services and allowing us to demonstrate the efficacy of our framework using site specific data without the use of new surveys or data collection.

Section 3: Material & Methods

Data for the New Waddell Dam was obtained from the United States Bureau of Reclamation (United States Bureau of Reclamation, 2020). The Dam was completed in 1994 and can store up to 1.1 million acre-feet of water. Data on recreation at the dam was obtained from the Maricopa County Parks and Recreation Department, including the number of annual visitors (Chhabra et al. 2014), as well as the primary activity of each visit (Budruk and Sampson 2019). Data for water withdrawn from the reservoir was obtained from the Central Arizona Project Subcontracting Status Report (Central Arizona Project, 2017). The report includes the annual withdrawals allocated to municipal and agricultural stakeholders. Energy prices were obtained from the Energy Information and Administration (EIA 2020), using the Palo Verde Peak data and the amount of energy produced from the Global Energy Observatory (Global Energy Observatory, 2010).

Table 3 provides a list of some of the potential types of values considered for this case study. In addition to the items that were valued, it includes benefits that were considered but not quantitatively valued. This type of list can be used as a blueprint for other valuations to show that as many types of benefits as possible should be considered. The table also includes valuation methods that could be used for each benefit type. Nonmarket valuation techniques may be required to value goods and services that are not traded on traditional markets. The valuation technique used do not typically depend on the type of stakeholder, so they are omitted from table 3 for brevity.

Benefit transfer can be used to obtain values when an original study is not feasible. Benefit transfer is not typically as accurate as an original study but has been shown to produce reasonably accurate results suitable for cost-benefit analysis (Johnston 2015, Richardson et al. 2015, Champ et al. 2017). Most of the valuation approaches listed here can be applied using benefit transfer.

○ TABLE 3: VALUATION METRICS AND APPROACHES

Description	Ecosystem Metrics	Economic Metrics	Valuation Approaches	Used in Case Study
Recreation	Number of trips per year	Value attributed to recreational activities; Willingness to pay (WTP) for access to recreational areas	Travel cost method; Contingent valuation	Yes
Land Use Lost	Area (km^2)	WTP for species preservation	Contingent valuation; Defensive expenditures	Yes
Stream Flow	Flow rate (cfs)	WTP for increased streamflow in recreational activities	Contingent valuation; Travel cost method	
Power Generation	KWh per year	Value of PHES power generation	Production function; Market observation	Yes
Net CO_2 Emissions	Tons per year	Value of social cost of carbon	Market observation	Yes
Electricity Price Changes	$ per KWh	Value to consumers from lower electricity price	Production function	No; Quantitative information unavailable
Commercial fishing	Harvested quantity	Profits to commercial fisheries	Production function	No; Commercial fisheries not present

Flood Control	Reduction in hazard rates of floods; Reduction in severity of floods.	WTP for reduced flood occurrence; WTP for reduced flood severity	Hedonic method; Contingent valuation	No; Quantitative information unavailable
Sediment Control	Tons per year	Cost of restoring shoreline Cost of filtering or cleaning sediment	Defensive expenditures Contingent Valuation	No; Quantitative information unavailable
Water Temperature Changes	Degrees (C or F)	Cost of restoring original temperature WTP for preservation of affected ecology	Defensive expenditures Contingent Valuation	No; Quantitative information unavailable
Groundwater Quantity	Volume (kgal)	Value of water availability; Shadow value of water as a renewable resource	Renewable resource model; Contingent valuation	No; Surface water only project
Groundwater Quality	Chemical and physical changes	WTP for restoring quality	Defensive expenditures; Replacement cost	No; Surface water only project
Educators and Research			Contingent Valuation	No; Descriptive information available
Spiritual and Ceremonial	Description of spiritual and ceremonial significance	-	-	No; Descriptive information available
Changes in Scenic Views	Description of changes in scenery	-	-	No; Description information available

Non-Use Values	Terrestrial habitat preservation (km^2) Aquatic habitat preservation (km or # of species)	WTP for preservation of non-users	Contingent valuation	No; Quantitative information unavailable
Water Level Changes	Depth and frequency of water changes	Reduction in WTP for recreational activities and scenic views	Travel cost method; Contingent valuation	No; Quantitative information unavailable

Section 4: Results

Table 4 reports the data used for calculating the value of this dam. The values are separated by category into the value of the power generated and the value of the externality.

○ TABLE 4: VALUATION OF THE NEW WADDELL DAM PUMPED STORAGE HYDROPOWER POWER PLANT.

Benefit Category	Benefit Type	Unit Value	Amount	Benefit Value
Energy	Electricity Generation	37.46[1] \$/MWh	47,200[2] MWh	1,770,000
	Electricity Consumed for Pumping	19.09[3] \$/MWh	-59,000 MWh	-1,130,000
Externalities	Land Use	-198 \$/acre	7,741 acres	-1,532,718
	Emissions	50 \$/ton CO2	-8,300 tons CO_2	-415,000

[1] Average value of June through October wholesale price for Palo Verde Peak Market. https://www.eia.gov/electricity/wholesale/#history

[2] http://globalenergyobservatory.org/geoid/1835

[3] Average value of November through May wholesale price for Palo Verde Peak Market. https://www.eia.gov/electricity/wholesale/#history

Benefit Category	Benefit Type	Unit Value	Amount	Benefit Value
	Metro Water Use	420,695 acre feet	$58 per acre-foot	24,400,000
	Agricultural Water Use	3,090 acre feet	45.54 per acre-foot withdrawn	141,000
Recreation[1]	Boating	34.97 $/Trip	151550 Trips	5,300,000
	Swimming	30.82 $/Trip	189621 Trips	5,840,000
	Fishing	78.83 $/Trip	62963 Trips	4,963,373
	Hiking	84.73 $/Trip	153015 Trips	13,000,000
	Jogging and Running	64.99 $/Trip	12446 Trips	809,000
	Camping	22.7 $/Trip	75409 Trips	1,710,000
	Horseback Riding	172.13 $/Trip	12446 Trips	2,142,000
	Mountain Biking	196.15 $/Trip	8786 Trips	1,723,000
	Picnicking	30.84 $/Trip	24892 Trips	767,700
	Diving	103.56 $/Trip	16839 Trips	1,744,000
	Other	40.17 $/Trip	24160 Trips	970,500
Total				**$62,200,000**

4.1Power Generated

The PHES facility at New Waddell Dam has a nameplate capacity of 45 MW. The value of the power generated is computed as the revenues received from sale of power on the wholesale

[1] All per trip values obtained from https://sciencebase.usgs.gov/benefit-transfer/. Average Value for the Intermountain region used for each activity.

market minus the cost of the electricity that must be used to pump the water (Iliadis and Gnansounou, 2016 and Koritaroc et al 2014). Data is not publicly available on daily electricity supplied and used. Assuming 75% efficiency, the average of 47.2 GWh generated per year requires 63.0 GWh to pump[1]. The value of this electricity generation is that it is pumped during winter, off-peak hours when power generation is low cost, and then the power is generated during peak hours when it can receive a higher price. The value of this power is the net of the cost of pumping to the power station and the revenues received from the sale of the power. Wholesale electricity prices were obtained from the U.S. Department of Energy for the Palo Verde Peak Price Hub[2]. The New Waddell Plant pumps mostly during winter months and provides power to the grid during summer months. Revenues received used the average high price from June to October, and costs used the average low price from November to May, omitting days when the price was over $30 per MWh. This assumes operators are able to optimize their pumping schedule to avoid high price days.

The value to electricity consumers from the operation of the plant should also be considered. Local residents may pay a lower price for electricity due to the inclusion of PHES because it is able to displace the high cost power that would be required during peak hours. The New Waddell Dam supplies less than 1% of the electricity demanded by the Phoenix metropolitan statistical area, so it is assumed that this benefit is negligible for this case study.

4.2 Externalities

[1] http://globalenergyobservatory.org/geoid/1835.

[2] https://www.eia.gov/electricity/wholesale/#history.

4.2.1 Recreational Opportunities

The primary externality created by the New Waddell Dam and Lake Pleasant is recreational opportunities. The Lake Pleasant area has around 700,000 visitors per year that come for swimming, boating, hiking, camping, etc. Around 10% of visitors come from out of state. The creation of this lake provides a variety of recreational activities that would not be available without the dam. The number of visitors for each activity is combined with a value per visit (Looomis et al. 2008) to obtain the total value for recreation.

4.2.2 Water Use

The dam also provides water that is useable for local agricultural and municipal drinking water use. The amount of water withdrawn per year is combined with a value per acre-foot to obtain the total value. The value of water for agriculture is obtained from Lowe et al. (2020). Over 420,000 acre-feet is withdrawn for municipal use per year, enough to supply over 1.2 million households. Demand based valuation of municipal water gives estimates of $231/acre-foot (Lowe et al 2020), yielding benefits as high as $91 million. However, the value of the water in the reservoir should be valued before treatment and distribution (i.e., the at-source value) (Young and Loomis 2014). The per unit value of water can be estimated by the sale price where a water market is present, however the price of water varies over time and by location. For this case study, we use $58 per acre-foot, which is the minimum price other utilities pay for water use on the Arizona water market[1].

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[1] https://uaatwork.arizona.edu/sites/default/files/2014_wrrc_arroyo.pdf

4.2.3 Land Use

The final externality measured is land use. The reservoir required flooding land that had been part of habitat for local ecosystems. The area of the reservoir is combined with a value per acre (Constanza et al 1997) to obtain the value that is lost from using previously unused natural land.

4.2.4 Carbon Emissions

Carbon emissions are calculated as a externality damages imposed on the global population. The power generation creates emissions due to the net power use required for pumping water. This value is calculated based on the emissions of the alternative power generation that would hypothetically occur if the PHES facility was not in operation. The power generated in the State of Arizona by source type is coal (35.5%) and natural gas (31.1%). It is assumed that nuclear (27.4%), hydro (5.8%), and other renewables (0.2%) do not create emissions. The net power required for the New Waddell Plant is 15.8 GWh per year. Coal provides 5.6 GWh of power, yielding 6,200 tons of CO_2 and 4.6 GWh being provided by natural gas, yielding 2,100 tons of CO_2. Using a social cost of carbon of $50 per ton of CO_2 (Rennert and Kingdon 2019) imposes a cost (negative value) of $415,000 per year.

Section 5: Discussion

Summing up all values listed gives us the total economic value of this dam and PHES facility. This value could be compared with the cost of building the dam to determine if the project is economically feasible. The total value for this case study is around $62 million per year, with the largest shares coming from municipal water use and recreation.

It is also possible to use these values to carry out stakeholder specific cost-benefit analysis. Economic values can be separated by stakeholder, and these values can then be used to determine if the project is economically viable for specific stakeholders. Traditionally, cost-benefit analysis has been done at the total economic value level to determine whether a project is valuable from a public policy perspective. Of late, however, there has been an increased emphasis on the distributional consequences of policy and a stakeholder specific cost-benefit analysis would be capable of addressing that question. For PHES projects, this can be done using a cost-benefit analysis for each stakeholder using a framework similar to the one proposed in this paper.

For example, the value could be computed for the company operating the plant, and it can be computed separately for a local resident who does not receive profits from the electricity generated but does enjoy recreation at the site. For this case study, local residents receive a significant amount of benefits from recreation that exceed the direct benefits of electricity generation from the PHES project. It is unlikely that revenues from the power plant alone would justify the cost of building the project ($625 million[1]). For a different project, a power plant may generate revenue large enough to make the plant profitable but create negative externalities large enough that local residents or recreationists are made worse off. In the future it may be worthwhile to consider how to compensate those who may be made worse off by construction of public projects.

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[1] https://en.wikipedia.org/wiki/New_Waddell_Dam

Section 6: Conclusion

Our study is the first of its kind to create a framework for the valuation of hydropower that can be directly imported and applied to other sites, after accounting for site specific features. The central limitation to our proposed approach is the high data requirements. Each benefit type requires data on the amount of the benefit that is provided by the PHES project, as well as a value in the literature that can be appropriately assigned to it. While funding may be available to conduct an original study to determine one or a small number of these values, it will rarely be the case that funding is sufficient to determine all benefits at a policy site. In practice, most studies focus specifically on what is believed to be the most important type(s) of value, with the other values computed using methods, such as benefit transfer given sufficient site-specific comparisons. For our case study too, this type of limitation is present in several of the benefit types.

A further limitation of our study (in the absence of the ability to conduct a primary survey) is the assumption we make when estimating the recreational benefits from the project. Specifically, we assign a starting value of zero (i.e., recreational benefits were zero before the project came into existence).

These limitations notwithstanding, our approach to value hydropower is more comprehensive than any extant methods and will permit policy analysis while also allowing one to understand the distributional consequences at the level of the individual stakeholders.

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