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Water Diplomacy from a Duck's Perspective: Wildlife as Stakeholders in Water Management

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Abstract: Contemporary water management strategies call for the inclusion of ecological research in the decision-making process and emphasize environmentally sustainable management solutions. Most ecological information used in water management shares two problematic characteristics; 1) simplistic, phenomenological approaches and aggregated data that may not properly describe system behavior, and 2) a "zero-sum" perspective treating ecological water needs as constraints to management. We argue that the newly devised Water Diplomacy Framework (WDF) can help overcome these shortcomings. We also provide a simple and intuitive method for integrating ecological factors into the WDF. We suggest that treating ecological phenomena as "surrogate stakeholders" in water negotiations increases opportunities for discovering mutual-gains solutions and encourages a hypothesis-based approach to research on the ecology of water management. By differentiating between the "positions" and "interests" of ecological stakeholder surrogates, decision-makers can make greater use of the potential added value of ecosystem services in water management and avoid costly misunderstandings of the behavior of relevant ecological systems. We outline how the WDF can be applied to better integrate ecological factors into water management, and show how our approach could create synergies between endangered waterbird conservation and sustainable water management on the island of Oahu, Hawaii.

Keywords: *ecosystem services, endangered species, environmental flows, IWRM, mutual gains, waterbirds, water policy, wetlands*

Water management problems in the new millennium increasingly involve multiple stakeholders with competing interests, managing shared and limited water resources under a high degree of technical and scientific uncertainty (Molle et al. 2008; Wagener et al. 2010; Islam and Susskind 2013). Interdisciplinary approaches are essential to create sustainable and effective solutions for this new generation of complex water problems. Frameworks like Integrated Water Resources Management (IWRM) encourage integration of knowledge across fields like water resources engineering, economics, and political science to generate effective solutions to modern water resources problems (Al Radif 1999; GWP 2000; Biswas 2004; Molle et al. 2008). For the last 25 years, increasing global awareness of the importance of ecosystems and biodiversity for human well-being (ICWE 1992; Millennium Ecosystem Assessment 2005; Duffy 2009; Hough 2014) has prompted the developers of leading water management strategies to incorporate ecological factors into the decision-making process (Tharme 2003; Arthington 2012; Liu et al. 2013). We define ecological factors as any ecological phenomenon (e.g., a species, population, habitat, ecosystem function, ecosystem structure, etc.) that is of interest for water management. It is now widely acknowledged that ecological factors are important to consider in water management, because they are influenced strongly by management action (e.g., Kingsford and Johnson 1998), and can greatly affect management outcomes by affecting the provision of ecosystem services (Postel and Carpenter 1997; IUCN 2000; Richter et al. 2003;

Poff et al. 2003). The growing impetus to include ecological factors in water management is made especially clear by their explicit inclusion in the core principles of IWRM (defined as Ecological Sustainability; GWP 2000).

Recognition of the need to include ecosystems in water management decision-making motivated the creation of theoretical frameworks capable of internalizing ecological factors into the water management equation. Such frameworks include natural or environmental flows (Poff et al. 1997; Tharme 2003; Arthington 2012) and environmental water (Beesley et al. 2014), ecosystem services valuation (Postel and Carpenter 1997; Brauman et al. 2007), and blue and green water (Falkenmark and Rockstrom 2004, 2006). Including ecological factors advances the water management process by forming the conceptual nexus between the alteration of natural water regimes, the resulting degradation of ecosystems, and the potential negative effects of such degradation on human populations and stakeholders. In practice, however, most contemporary approaches to ecologically informed water management share two characteristics that we view as problematic (see Table 1A):

> **Problem 1.** Ecological factors used in water management research most often consist of coarse-scale ecological data (e.g., species richness), that are spatially aggregated, or they describe the behavior (response) of only one taxon or guild in an ecosystem, and thus may not adequately characterize the dynamics of the ecosystem.
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> **Problem 2.** Ecological factors are typically presented or integrated into decision-making in the form of constraints on water management solutions, resulting in a focus on trade-offs and mutually-exclusive allocation of water between human and ecological needs.

Problem 1 arises when data are collected at large ecological or spatial scales in order to summarize the characteristics of the ecological systems affected by water management decisions, such as when the condition of a river is measured by the number of fish species within it (e.g., Cui et al. 2010). Such data are often used because they are relatively easy to collect and interpret, and they operate on scales similar to the hydrological models developed by engineers for comparing management strategies (Mollinga et al. 2006; Xenopoulos and Lodge 2006). Thus, these data are a convenient way to integrate ecological factors into management via hydrological models. Basing decisions of scale and resolution of ecological data on convenience increases the probability of mischaracterizing the behavior of the ecological system in question and missing important system dynamics that may have profound effects on management outcomes. For example, using the abundance of a single fish species as an indicator of ecological health and basing minimum flows for a river on that information might result in failure to detect shifts in community structure that occur independently of the abundance of the indicator species. Some animal species will shift their diets or feeding habits in different environmental contexts, thus having different impacts on other species in the system (e.g., Kushlan 1986); others cannot make such shifts, and are thus especially sensitive to hydrological alteration (Rubega and Inouye 1994). For example, Balcombe et al. (2005) found that some fish species in a floodplain river in Queensland, Australia dramatically changed their diets depending on river flow (flooding vs. non-flooding). Failure to detect such shifts in community structure might lead to unanticipated management outcomes, for example trophic cascades that affect ecosystem processes like primary productivity and nutrient retention (Brett and Goldman 1996; Baxter et al. 2004). Although this problem is of interest and will be touched upon in this paper, we are more interested in Problem 2, and will save a more in-depth analysis of Problem 1 for a later publication.

Problem 2 is driven by the process by which water management decisions are made, and the point at which ecological information is used in that process. Generally, ecological information is used later in the decision-making process, after management strategies have been decided upon, and it is used to place limits on operations or present ecosystem trade-offs that must be weighed (Mollinga et al. 2006; Chisolm 2010; Sanon et al. 2012; Willaarts et al. 2012). In the case of water

Table 1. (A.) Reference list of potential problems with current interdisciplinary water management approaches. (B.) Four selected tenets of the Water Diplomacy framework that are useful for improving use of ecological research in water management.

A.) Problems with contemporary water management	B.) Selected tenets of Water Diplomacy Framework
1. Information on ecological factors is often spatially aggregated or based on assumptions of surrogacy, and focuses on correlative rather than mechanistic relationships.	I. Defining analytical scale and boundaries using network and complexity theory II. Prioritizing actionable knowledge III. Treating water as a flexible resource IV. Using a negotiations approach based on mutual gains
2. Ecological factors are typically integrated late in the decision-making process, or treated only as constraints to management options.	

diversions for agricultural irrigation, for example, the infrastructure for irrigation will already have been decided upon, but the needs of riparian ecosystems for in-stream flow are considered post-hoc as a means of constraining withdrawals and ensure a minimum in-stream flow to support ecosystems (Richter et al. 2003; Mollinga et al. 2006). While this is one way to ensure that enough water is provided for specific ecological systems, such hard and fast rules fail to convey why constraints like minimum flows are set, and what role the allotted minimum flow plays in the affected ecosystem. There is little room for leeway or more creative solutions, particularly when water is scarce; furthermore, the "constraints", or zero-sum mindset can create negative public attitudes toward environmental water needs (Moore et al. 1996; Votteler 1998; Wallace et al. 2003). Zero-sum thinking can also become a self-fulfilling prophecy, whereby decision-makers ultimately create management that results in situations where benefits to stakeholders are mutually exclusive (Islam and Susskind 2013). For example, water management of the Danube River in Europe led to two failed management plans, the first favoring economic gain at the expense of ecological integrity, and the second favoring ecological restoration over economic development (Islam and Susskind 2013).

It should be noted that both problems 1 and 2 are natural results of the complexity and urgency of the water management issues faced by decision-makers; decisions are often made with limited monetary resources and time, leading to simplification of ecological metrics, and constraints are used as a precautionary measure to avoid unacceptable losses that might occur from misunderstanding ecological dynamics. This simplification of both options and data are considered necessary steps to include ecological factors in management when decision-makers may have poor understanding of ecological dynamics (Schiller et al. 2001). We do not question that decisions must be made under uncertainty - this is nearly a defining characteristic of modern water management - but we do not want water managers to limit themselves to low quality information and hard constraints when available knowledge may offer better solutions. Improved frameworks for integrating ecological information into water management should thus contribute to overcoming these problems while also making ecological data more accessible to decision-makers.

Water Diplomacy is an emerging water management framework that operates from a negotiations-based approach to decision-making in the context of complex water problems (Islam and Susskind 2013). Several of its core principles provide potential solutions to the problems outlined above, and we assert that methods integrating ecological factors into the Water Diplomacy Framework (WDF) can lead to improved solutions in water management. Currently, the WDF has no formal protocol to integrate ecological information. In this paper, we propose that ecological factors, especially focal species, can be easily integrated into the WDF when treated as "surrogate stakeholders"; that is, when such variables are treated in a functionally similar manner to actual stakeholders in the negotiations process of Water

Diplomacy. We suggest that considering ecological factors early in water allocation decision-making, and treating water allocation as a non-zero sum game (i.e., allowing for mutual gains), expands options for creating sustainable management solutions. Ecological factors like focal species (those of economic, cultural, ecological, or conservation importance), entire ecosystems, and indices of ecological integrity (e.g., Karr 1991; DePhilip and Moberg 2010; Clapcott et al. 2012) can act as surrogate stakeholders. We support this surrogate stakeholder approach for the sake of practicality, and not with any normative intention of asserting that species, ecosystems, or other natural phenomena are capable of having interests or have their own ethical standing; such philosophical questions are outside the scope of this paper. We do suggest, however, that this method makes complex ecological information more readily attainable to decision-makers and expands its possible use in creating feasible management solutions. We describe this approach below and illustrate how it expands management options in the case of water management on the island of O`ahu, Hawai`i (USA).

Advantages of the Water Diplomacy Framework (WDF)

The core tenets of the WDF (see Table 1B) include I) the use of network and complexity theory to define the scale of analysis and boundaries of the water management problem; II) an emphasis on "actionable" knowledge - that which is easily grasped by stakeholders and answers research questions crucial to decision-making - and applied research; III) treatment of water as a "flexible resource", acknowledging the potential importance of water throughout the hydrological cycle and the role of order of use in maximizing benefits to stakeholders; and IV) using a negotiations approach based in mutual gains (Susskind and Islam 2012; Islam and Susskind 2013).

Tenet IV is perhaps the most novel for water use negotiation and it is the most important of the concepts for overcoming Problems 1 & 2 identified above. The negotiations framework convenes stakeholders with potentially competing interests and uses mutual gains negotiations to create and highlight solutions that benefit the interests of all stakeholders (Islam and Susskind 2013). Mutual gains negotiations avoid zero-sum thinking and shift the dynamics of stakeholder interaction from competition to value creation, such that stakeholders can find mutually beneficial outcomes without sacrificing their self-interest (Fisher and Ury 1991; Susskind 2008). A chief goal of mutual gains is disabusing stakeholders of the notion that their interests can only be met at the expense of other stakeholders (Fisher and Ury 1991; Islam and Susskind 2013). Mutual gains or non-zero sum thinking is viewed by some as the best approach to overcoming water management issues, especially in the case of transboundary water resources (Islam and Susskind 2013; Dema 2014). As an ecologically-relevant example, a zero-sum view is that water can either remain in a wetland to support fishing or can be diverted for agricultural irrigation; a non-zero sum view recognizes that rainfall can be captured in a wetland for use by fish, and then infiltrate into groundwater for subsequent human uses (e.g., Musu 2001; cf. Dema 2014).

Mutual gains negotiation differentiates between the positions and interests of stakeholders with respect to the shared resource - this allows stakeholders to view one another not as constraints but as entities with flexible needs resulting from a particular set of values. Interests are the direct product of a stakeholder's values, defining what they actually need to get out of the negotiations process; this might be sufficient water to support agriculture, or the need for a diplomatic official to maintain face and protect the reputation of his or her constituents (Fisher and Ury 1991; Islam and Susskind 2013). Interests are the needs and values that motivate positions, the spoken, manifest demands or perspectives presented by a stakeholder during negotiations over the management of a shared resource. Positions might include an unwillingness to allow dam releases at certain times of year, or a request that a specific amount of water be set aside for irrigation (Fisher and Ury 1991; Islam and Susskind 2013). Interests, by contrast are tacit, often hidden, and ultimately less flexible. For example, it might be culturally or politically unacceptable to force farmers to abandon their lifestyles simply due to water demands, but the positions that arise from

these interests are often much more negotiable. If irrigation releases cannot be increased to match the position of rural farmers, the underlying interests of that position - that of making greater profit from the management of their land, and maintaining their livelihoods and lifestyles - might be satisfied by subsidizing transitions to more profitable crops with lower water demand, higher-efficiency watering equipment, or alternate forms of income through farmland management (e.g. ecotourism; Pooler 2013). These could sustain income, satisfying basic interests, while altering the farmers' position. Creative alternatives can satisfy the interests of a stakeholder while circumventing the problematic aspects of their original position; in this case, a demand for water diversions that might be untenable considering the rest of the system. This process of meeting interests - rather than positions - by providing benefits from sources originally external to the system is called "adding value" (Islam and Susskind 2013). Applying this framework to ecological systems would enable decision makers to treat ecological factors as potential opportunities for added value among stakeholders and not as constraints on available options (Problem 2).

Tenets I and III relate most strongly to the beginning stages of the WDF workflow, particularly in the process of convening stakeholders, defining the boundaries of the water resources problem, and exploring potential solutions (Islam and Susskind 2013). Using a network or systems approach (Tenet I) emphasizes functional linkages, be they ecological, economic, political, or social, between various stakeholder groups. Linkages might include economic benefits of water purification provided by a riparian wetland to a downstream city, the cultural importance of a fish migration to a First Nations people, or the exchange of virtual water between two countries through agricultural commerce (Allan 1998). The network approach can thus be used to model and internalize interest groups that might normally be overlooked or managed separately - such as endangered or economically important species. Understanding the relationships between stakeholders also helps recognize the broader boundaries of the water problem. While most traditional engineering approaches to water management delineate the watershed as the boundary of any water management problem, the effects of water management can be felt far beyond watershed boundaries. As an example, if pollution in a coastal city affects its fishing yields, neighboring states are affected even if they are not using that water but are sharing the economic burden through trade. This expanded view of the problem's boundaries identified through non-hydrological variables is known as the "problemshed". Ecological problemsheds might be limited to the watershed, or can extend far beyond it. Many waterbird species cross continents in annual migrations, passing through many watersheds, effectively linking the impacts of management within each of those areas (Bauer and Hoye 2014). Migratory birds have become a key driver in encouraging transboundary cooperation throughout the world, including U.S.A-Canada (Dorsey 1998), Israel-Palestine (Leshem et al. 2003), and U.S.A-Cuba (Boom 2012).

Expanding viewpoints to the problemshed level seems at first overwhelming and counter-productive, as though it might add too many constraints to the system. However, as part of the WDF, framing the problemshed and acknowledging the complex interactions of various system components in a network actually aids the process of adding value by increasing the pool of potential interests that can be aligned and satisfied.

Once the problemshed has been identified, Tenet III becomes important in designing integrated management solutions by expanding the ways in which water is viewed and valued within the system. Water is most often viewed as a finite resource - particularly as a sum of fresh surface or groundwater to be divided amongst interested parties. However, water has many other values and functions in ecosystems and economies that are often unacknowledged. Taking a narrower view reduces opportunities for mechanistic understanding of system behavior and for adding value in mutual gains negotiations. Following Tenet III, researchers should pay attention to the role that water plays in stakeholder interests throughout the hydrological cycle, and not focus only on, for example, water provision as its sole function. For instance, evaporating water from irrigation can influence regional meteorology,

changing rainfall patterns in nearby but separate watersheds (Lo and Famiglietti 2013). Water is also a highly effective transporter of nutrients, sediments, salt, and other chemical agents that may be beneficial or detrimental to human or natural systems, and failure to recognize this function can have severe consequences (e.g., Harris 1991; Schepers et al. 1991; Jaeger et al. 1999). For example, many wetland ecosystems provide under-recognized hydrological benefits to adjacent human settlements in the form of meteorological "oasis effects" (Polcher et al. 2008) and by recharging groundwater (e.g., van der Kamp and Hayashi 1998).

Employing Tenet III further enlarges the problemshed created by Tenet I, leading to a more holistic understanding of the system being managed and the impacts of potential management actions. Ultimately, these two tenets internalize stakeholders and processes that were formerly treated as external to water management problems, and could help to resolve Problem 2 (treating target species and ecosystem water needs as constraints), by facilitating mutual gains negotiation and including species as stakeholders, and Problem 1 (inadequate ecological metrics), by requiring a more systematic and thorough understanding of ecological dynamics than is typically considered.

Finally, Tenet II demands that data collected for water management are actionable (Islam and Susskind 2013). Actionable knowledge comes from applied research designed to answer questions about system dynamics that are of concern to stakeholders. Once previously-external stakeholders and linkages have been internalized (via Tenets I & III), targeted research creates a shared knowledge base for all stakeholders. This joint fact-finding process either reduces or clarifies and quantifies uncertainty about the dynamics of the system to be managed (Islam and Susskind 2013). It can also build trust and enhance cooperation for later mutual gains negotiations. To be actionable, research must be adequately detailed to describe important elements of the system's behavior, but also be in a format that can be easily integrated into the negotiations process. Thus, Tenet II could address Problem 1 by ensuring that ecological research is focused on processes important to the functioning of the ecological system(s) in question, thus enhancing integration into the decision making process. Finally, it addresses Problem 2 by necessitating that ecological data take a form amenable to a negotiations approach.

Ecological Factors as Surrogate Stakeholders

Although the Water Diplomacy Framework (WDF) has characteristics that would improve how ecological factors can be integrated into water management, there remains the problem of fitting ecological factors conceptually within the framework in such a way as to be implementable. We propose that this can best be done by treating ecological factors as surrogate stakeholders; that is, as entities that have specific interest and position analogs that can be integrated into mutual gains negotiations and potentially used to add value, rather than simply act as constraints.

For actual stakeholders, positions are the external manifestation of internal interest; an ecological factor's position is a combination of its response to manipulations of the water resource, and societal and cultural values attributed to that response. In other words, a surrogate stakeholder's position is its observed reaction to changes in the hydrological regime, as indicated by a chosen set of ecological indicators, plus some social determination of whether those changes are good or bad for the system. Examples of ecosystem positions may include an increase in native emergent aquatic plant cover, an increase in dissolved oxygen or aquatic nutrient load, increased salmon abundance, or decreased sediment transport. In the case of a target or focal species approach, a species' position might be described by increased or decreased abundance — perhaps with respect to the fulfillment of an ecological role (e.g., Soulé et al. 2003), increased reproductive success, an expanded range, etc. The positions of ecological surrogate stakeholders are products of a purely phenomenological understanding of ecosystem dynamics; they are based on simple observations of how a target species or ecological indicator responds to changes in the system. What an ecosystem is observed to do in response to a management action dictates its

position with respect to a resource. However, the implications of this behavior - that is, its value, whether it is considered good or bad - cannot be provided by the surrogate stakeholder.

Unlike real stakeholders that can articulate their own values, the value of management outcomes with respect to surrogate stakeholders' positions must be based on values attributed a-priori by some external agent. In other words, it is unclear whether the behaviors listed above (increases in abundance, changes in dissolved oxygen) are considered negative or positive until they are given some value in the context of the socio-ecological system. In a given hydrological system, if 95% of avian diversity is lost when water levels rise more than 60 cm in a pond, that is the ecosystem's response, but it is not an informative position unless given some value by society at large or some subset within it. If decision-makers and other stakeholders have decided that avian declines are unwanted, then the behavior described above shows a negative consequence to be avoided. The position of the ecosystem is thus that the pond's water should not rise beyond that threshold. In this way, the "position" of an ecological factor is a combination of its observed behavior and cultural values that specify whether certain behaviors are desirable or undesirable. This level of analysis is where most water management frameworks stop ecological analysis, and incorporate these dynamics into water management plans as direct constraints. The Water Diplomacy Framework encourages ecological research to proceed to deeper levels of analysis when treating ecological factors as surrogate stakeholders.

Because they are not actual stakeholders that can be consulted directly, ecological surrogate stakeholders' positions and interests are determined by empirical ecological research. The "interests" of an ecological system are causal, mechanistic relationships that explain the observed phenomena of position analogs. Just as a farmer's interests explain the underlying values that bring about their manifest positions, ecological interests are the actual causes that generate an ecological factor's observed response to changes in the hydrology of the system. A wetland's position might be that marshgrass diversity (a desirable trait of the system, in this case) decreases after water levels are reduced by residential water use. The wetland's interest is the mechanism causing this response; perhaps lower water levels allow competitive exclusion of some marshgrass species by others. Other means of maintaining marshgrass diversity - perhaps the use of occasional floods or physical disturbance like mowing - might satisfy the wetland's interests (i.e., the need to maintain species diversity, a desired trait in the ecosystem) without compromising residential water needs as apparently necessitated by its original position. Focal species' interests are typically behavioral and more analogous to the interests of human stakeholders; for example, beavers build dams to increase their reproductive fitness and survival (Naiman et al. 1988). Mechanistic understandings of these behaviors can lead to better management of human-wildlife conflicts caused by such behaviors. Several devices have been designed to prevent beaver dams from flooding roads and residential areas using detailed knowledge of the behavioral cues beavers use for dam-building (Payne and Peterson 1986; Nolte et al. 2000; Jensen et al. 2001). These devices save managers the energy and expense of beaver control alternatives like killing or relocation, while beavers are able to perform their natural behaviors undisturbed and without causing destructive floods.

Because Water Diplomacy is an emerging framework, and because our suggested role for ecology within this framework is particularly new to water management, we are unable to find any concrete examples of our suggested approach in action. However, cases exist that validate different aspects of our approach. One of the most famous examples of the enhanced, mutual-gains outcomes that can be created using a negotiated approach is the New York City Watershed collaboration. In the 1990's, the City of New York was getting about 90% of its water from the rural Catskill-Delaware watershed, and due to land practices within the watershed, the quality of this water was at risk (Hoffman 2010). Rather than forcing cooperation from farmers in the Catskill-Delaware, the city negotiated a memorandum of agreement with them that led to mutual gains (Daily and Ellison 2002; Postel and Thompson 2005). Instead of spending an estimated $6 billion on a water filtration plant

with $300 million annual operating costs, the city spent $1.5 billion on helping farmers improve their lands to prevent erosion and contaminated runoff. Landowners were able to voluntarily participate in a program they helped design and received funding for restoration and enrichment of their properties (Postel and Thompson 2005).

The recent trend among conservation biologists toward including more detailed, mechanistic research (especially regarding behavior) in wildlife conservation (Reed 2002; Blumstein and Fernandez-Juricic 2004; Caro 2007) illustrates the increased utility of seeking ecological "interests" when solving environmental problems. Inquiry into the behavioral and physiological mechanisms of observed species responses has led to improved predictions of species distributions in response to climate change (Kearney et al. 2010), risk of pest establishment (Kumar et al. 2014), and effectiveness of protected areas (Kujala et al. 2011).

The ability of ecological factors to provide added value in negotiations is readily apparent in recent research on ecosystem services; the services provided by wetlands are especially relevant to water conservation. While constructed wetlands have been used for decades to treat wastewater effluent and simultaneously provide wildlife habitat (e.g., Worrall et al. 1997), more recent developments like the Qunli stormwater park (Saunders 2012) and the reconstruction of the Bezai community in China (Wang et al. 2006) extend the concept to impressive scales. These integrated eco-urban environments require an understanding of wetland ecology, and yield simultaneous benefits in wildlife support and stormwater treatment (Campbell and Ogden, 1999; Wang et al. 2006; Scholz et al. 2007).

To illustrate specifically how our proposed framework might lead to better water management solutions, we describe below a hypothetical application of our framework to water management on O`ahu, Hawai`i.

Case Study: O`ahu, Hawai`i and Endangered Waterbirds

The island of O`ahu, Hawai`i supports a rapidly-growing human population under vulnerable hydrological conditions. Nearly 100% of the island's natural freshwater is stored in basal aquifers that are threatened by overdrafting and sea level rise (Lau and Mink 2006; Liu 2007). Intense urban development and recent declines in agriculture have reduced infiltration and increased runoff (Ridgley and Giambelluca 1991; Giambelluca et al. 1996). This leads to floods and the contamination of offshore waters, which threatens tourist beaches, offshore fisheries of cultural importance, and coral reefs (Banner 1974; U.S. EPA et al. 2004; Leone 2006; U.S. Bureau of Reclamation 2008). The island's limited freshwater originally supported extensive coastal freshwater marshes, of which 70% have been lost to development (van Rees and Reed 2014), leading to declines in the island's endemic waterbird species, of which only 6 of the original 27 species remain (Scott et al. 2001). Four of these species still persist in breeding populations on O`ahu, where increasing habitat protection is considered a key part of ensuring the persistence of their populations (Reed et al. 2011; USFWS 2011).

Water resources management on the island has until recently been considered inefficient and possibly inequitable (Derrickson et al. 2007; Gopalakrishnan 2007), and has focused primarily on addressing only one aspect of the hydrological cycle, the availability of freshwater, at the expense of other important factors like runoff and infiltration (Oceanit et al. 2007; U.S. Bureau of Reclamation 2008). Additionally, it has largely neglected the ecological systems, like near-shore fisheries, coral reefs, and coastal wetlands, which are all affected by water and land management on the island. The resulting water management plans focus only on a single group of stakeholders - those interested in increased groundwater and freshwater availability - and suggest management techniques like deep injection wells, desalination plants, or diversions of highly contested river flows to meet increasing water needs (Oceanit et al. 2007; U.S. Bureau of Reclamation 2008). These strategies are likely to be very costly, have potential environmental impacts, and are unlikely to be socially acceptable in the context of past water resources disputes on the island (Gopalakrishnan et al. 2005).

By expanding the problemshed to include the island's historical context of wetland loss due to land development and water diversions (van Rees

and Reed 2014) and the economic and cultural importance of coastal and near-shore ecosystems (Birkeland 2004; Carl 2010), one can add a suite of ecological surrogate stakeholders and their relevant ecological processes (services) to the decision-making process (Tenets I & III). Their positions (for example, endangered waterbirds require increased wetland habitat, and coral reefs and fisheries require less-polluted runoff) might not be met by currently supported methods of increasing freshwater availability. Including these surrogate stakeholders in the decision-making process can yield added value to certain management strategies that are capable of meeting multiple needs simultaneously (Tenet IV).

For example, constructed wetlands are an increasingly popular and highly successful water management tool for reducing floods, increasing groundwater infiltration, and filtering sediment and nutrients from runoff (Magmedov et al. 1996; Mitsch and Gosselink 2000; Thompson 2002). Such wetlands may be an excellent solution to many of O`ahu's water management problems, and would cost a fraction of the expense of alternatives under consideration (Oceanit et al. 2007; U.S. Bureau of Reclamation 2008). Increased coastal wetland cover could reduce and purify runoff that is harming offshore ecosystems, while serving other stakeholder interests in reducing floods and potentially increasing groundwater recharge. At the same time, they could provide habitat for endangered waterbirds and offer opportunities for ecotourism and environmental education. Wetlands are often constructed specifically as habitat for waterbirds (Davis 2008; Rajpar and Zakaria 2013) and wetlands designed for hydrological benefits could likely be easily managed to provide habitat for endangered waterbirds at the same time (Zhang 2008). Applied ecological research into the habitat use and selection by endangered waterbirds (e.g., their movement habits and indicators of habitat quality), or the effects of different types of runoff on coral reefs and culturally important fish would yield further information on how best to implement mutual-gains solutions. If, for example, endangered waterbirds had less need for larger wetlands for breeding, but instead benefitted more from smaller "stepping-stone" wetlands to facilitate movement throughout the landscape (Amezaga et al. 2002), a smaller, more decentralized approach to wetland design might be used while de-centralizing runoff control benefits. This higher level research into the interests of relevant ecological factors would clarify the feasibility of targeted, integrated solutions to multiple water management problems on the island.

While it is beyond the scope of this paper to quantitatively evaluate the economic, social and political benefit of such an integrated solution, it does provide a clear example of how the inclusion of ecological surrogate stakeholders expands water management options to include mutual gains solutions that might ultimately result in more sustainable outcomes. Detailed analysis of the economic and social benefits of such a proposal would be necessary before choosing such integrated methods over more traditional approaches.

Discussion

Treating ecological factors as surrogate stakeholders would allow decision-makers and water managers to take advantage of the benefits of the WDF, especially the ability to develop mutual gains solutions. Understanding the interests of ecological surrogate stakeholders requires hypothesis-driven, rather than purely observational research, and thus involves the integration of ecological theory into data collection for water management decision-making. Such hypothesis-driven research, performed in the context of established theory, is generally thought to be a more effective form of scientific inquiry than purely observational studies (Platt 1964). In this way, viewing ecological factors as surrogate stakeholders can create the impetus for more rigorous scientific inquiry into the dynamics of hydrological and ecological systems, and drive progress in the ecology of water management. This research is also encouraged by the tenets of the WDF (Tenets I, II, & III) that call for internalization of ecological surrogate stakeholders characteristically left out of water management, recognition of the complete problemshed created by ecological linkages within the managed system, and the need

for research to be targeted to important applied issues. Finally, viewing ecological factors as surrogate stakeholders simplifies their involvement to a format that may be more accessible to decision-makers with no background in ecological science. Ecological information then becomes packaged in a way that is more familiar to politically-trained professionals and can be integrated into their general workflow. This method also shifts the integration of ecological factors in engineering approaches from a constraint near the end of the decision-making process to a surrogate stakeholder at the beginning of the process, when there is greater flexibility in the selection of management options.

As noted earlier, constraints with regard to ecological systems are often part of a precautionary approach to water management employed under conditions of uncertainty. The difficulty of actionable ecological research in water management problems is partly responsible for this uncertainty; studies often have a limited timeframe and budget. Additionally, the type of large-scale ecological manipulations needed to anticipate the effects of management decisions are often infeasible, and comparative studies can be confounded by differences between different ecological and hydrological systems (e.g., Mazzacano and Black 2008). The precautionary approach is typically the most prudent approach under such circumstances of forced uncertainty, but it should be acknowledged that opportunities for mutual-gains outcomes can be missed if this precautionary approach becomes a default, even in cases where better ecological information is available.

While our goal is to emphasize how more effective management solutions can be discovered by taking a mutual-gains negotiations approach reaching beyond such constraints, it should be acknowledged that for all natural systems there exist certain boundaries and constraints that are non-negotiable. That is, there is always a point at which ecological systems can no longer sustain processes and services, and no amount of ecological research or negotiation with surrogate stakeholders can circumvent such constraints. Our suggestion is not that our methodology allows ecological limitations to be bypassed altogether, but instead that receptiveness to new information and an adaptive approach to decision-making can yield superior management outcomes where time and information are available. Understanding the ecological positions and interests - especially those which are entirely non-negotiable - is at the core of this process, and empirically-supported environmental regulations that delineate the ecological "bottom line" greatly facilitate its functioning.

Additionally, the role of the environmental negotiator deserves careful attention; individuals that represent the interests or positions of environmental factors may not be at liberty to negotiate freely on the condition of natural resources that are often held in the public trust. It is consequently important to give adequate consideration to the social values we described that ultimately attribute positive or negative value to ecological interests, and insure that the needs of affected parties are acknowledged therein.

We do not claim that advocating the use of ecological factors as surrogate stakeholders in water management is novel or unique. The idea has been thoroughly discussed in business ethics literature, with specific regard to the more philosophical questions avoided in this text (Starik 1995; Jacobs 1997; Phillips and Reichart 2000; Driscoll and Starik 2004). Additionally, the idea of integrating human and wildlife resource needs has been prominent and heavily debated for some time, gaining special attention with the creation of reconciliation biology in the early 2000's (Rozensweig 2003; Geisler 2010). We propose that our more formalized approach may provide a convenient theoretical framework for implementing the type of ecological thinking generated by reconciliation biology in cases where resource-sharing is both necessary and unavoidable. This is especially important in cases where natural systems are given lowest priority among many stakeholders competing for use of a water resource. The growing emphasis on integrated water resources management requires constant improvement of the contributions of various disciplines to the process of water management, and we believe the approach outlined above may be the next step forward for the successful interaction of ecological science and water management. In order to implement this new perspective, further research is needed to define the types of ecological metrics that are most amenable to understanding surrogate stakeholder positions and interests while

minimizing cost and effort. Additionally, applied, hypothesis-driven research will help inform more contextually appropriate water policy and strengthen ties between ecological experts and the decision-makers who govern water management.

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