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May the Odds Be in Your Favor: Why Many Attempts to Reoperate Dams for the Environment Stall

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Abstract: The provision of flows for the environment, e-flows, is a means to restore the benefits of naturally flowing rivers. Despite the development of numerous methodologies to determine e-flows and optimize dam releases, actual implementation is relatively limited. Examples of successful e-flows implementation through dam reoperation exist in scientific literature; however, there is a missing narrative on cases where dam reoperation has been attempted but not successfully implemented. This study explores this impasse narrative and presents four hypotheses for further research on this subject: (1) Scientists are important stakeholders in the process of dam reoperation, but should play a supportive role rather than drive the process; (2) In undertaking scientific studies for determination of e-flows, a consensus on the priorities, knowledge gap, and solutions must be reached together with local stakeholders; (3) Local-level legislation and policy on e-flows provide the enabling environment for dam reoperation for e-flows; and (4) Genuine, carefully designed consultations of, and negotiations between, stakeholders can overcome hurdles encountered in the process of dam reoperation for e-flows implementation. **DOI: 10.1061/(ASCE)WR.1943-5452.0001521.**

Author keywords: Environmental flows; Reservoir operation; E-flow implementation hurdles; Flow restoration.

Background

Environmental flows (e-flows) are flows to sustain or restore freshwater and riparian ecosystems (Poff et al. 1997; Bunn and Arthington 2002; Tharme 2003). Providing e-flows represents a shift in water management from a purely human-centered endeavor to one that recognizes that a certain "quantity, timing, and quality of freshwater flows and levels [is] required to sustain aquatic ecosystems which in turn support human cultures, economies, sustainable livelihoods, and well-being" (Brisbane Declaration 2007). The concept of e-flows has gained traction in recent years. This is evidenced in the numerous methodologies that have been developed to determine e-flows for rivers and also to optimize dam releases (Tharme 2003; Pitta et al. 2010; Yin et al. 2011; Olivares et al. 2015; Mao et al. 2016; Slinger et al. 2017; Horne et al. 2018; Stamou et al. 2018; Owusu et al. 2021a, b).

Although dams are considered one of the main causes of degrading riverine ecosystems through alteration of river flow regimes, they can also provide the means of implementing e-flows through dam reoperation. Dam reoperation, the change in flow release practices to accommodate downstream aquatic ecosystem needs, thus represents an important approach to maintaining or restoring some of the benefits that free-flowing rivers provide. Notably, although theories and concepts for e-flows abound, actual implementation has remained minimal to date (Tharme 2003; Warner et al. 2014; Horne et al. 2016; Arthington et al. 2018; Brown et al. 2020; Owusu et al. 2021b). For instance, a systematic literature review of dam reoperation for e-flows revealed only 69 documented cases spanning the period 1983 to 2014 (Owusu et al. 2021b). These successful cases served to identify important factors in facilitating the implementation of e-flows, namely, the existence of e-flows legislation or policy, the development of a research base in the form of an environmental impact study, and flow experimentation (Owusu et al. 2021b).

The documented cases of successful dam reoperation tell one side of the story because the literature review did not reveal cases where dam reoperation was attempted or recommended but not actually implemented. Information on such stalled processes is crucial to deepen understanding of how dam reoperation processes can be facilitated to increase the likelihood of success. However, stalled cases have not yet been reported in the scientific literature. The aim of this study was to fill this gap and identify where the differences lie between successful and stalled dam reoperation attempts by investigating the variables identified through the systematic literature review of Owusu et al. (2021b) on how dams are reoperated. These variables were categorized based on a logic model of the process as the inputs to dam reoperation, the activities undertaken during the process, and the output of the process (Owusu et al. 2021b).

Furthermore, in this study, we also compared who was involved in the process (stakeholders), what dams they worked on (location and original purpose), and why the release of e-flows was desired in the first place (motivation). For instance, does the difference in success lie in the inputs to the process of dam reoperation such that

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some inputs (e.g., a scientific research base or supporting legislation) lay a better foundation for dam reoperation to occur? Or does the distinction lie in the original purpose for which the dam was operated such that certain water uses (e.g., hydropower, irrigation, or recreation) are more easily aligned with the release of e-flows? This study endeavored to answer these questions. Additionally, the main hurdles encountered in the process of dam reoperation and how these were successfully overcome on the one hand, or how these stalled the process on the other, were investigated.

To this end, a survey of dam operators, water managers, and other stakeholders with wide-ranging experience in dam reoperation for the release of e-flows was conducted. The survey method formed the favored approach for this study because it facilitates access to both published and nonpublished data on individual cases of dam reoperation from those with first-hand knowledge of the process.

The significance of this study is that it complements and deepens the understanding of dam reoperation for e-flows obtained from the systematic literature review of Owusu et al. (2021b). It also provides information to water resource planners and allocation optimizers on hurdles to dam reoperation. Furthermore, this study is also of relevance to people studying the concept of impasse, deadlock, or "stuckness," which refers to the gap between what we know to be desirable and achieving this desired outcome in practice (Bolten 2009; Shomura 2016). In environmental management, this concept extends beyond the field of e-flows, and indeed water resources management, to environmental conservation and management (Bryant 1997; Biggs et al. 2017), postconflict reconstruction (Kreimer et al. 1998; Bolten 2009), and policy transfer (Minkman et al. 2019). As such, this study adds insights on the conditions that contribute to hindering the desired management practice outcome of dam reoperation for e-flows and vice versa.

Following a more detailed explanation of the methods adopted ("Methods" section), the results of the survey are presented ("Results" section). The findings are then discussed with a particular focus on the hurdles to successful implementation in the "Discussion" section, before the paper concludes in the "Conclusion" section.

Methods

Selection of Variables for Investigation

How Dam Reoperation Occurs: Logic Model

This study adopted a logic model framework to understand the process of dam reoperation for e-flows (see Fig. 1 in Owusu et al. 2021b). For clarity, dam reoperation in this study refers to the change in the operation of a dam that hitherto was operated solely for conventional purposes such as hydropower generation, irrigation, flood control, or others, to now release flows for the environment as part of its operation. As such, the focus was on dams where there has been a modification, or an attempted modification, of operations to improve downstream riverine environments.

Logic models are flow diagrams that show the inputs, activities, outputs, outcomes, and impacts of a project (Yin 2009; Kneale et al. 2015). With respect to dam reoperation, the (desired) output is a change in flow release practices to release e-flows for downstream ecosystem needs. Inputs represent the drivers, actions and conditions that lead to a recommendation or decision to reoperate dams, and activities are the practices adopted to implement the decision to reoperate the dam (Thissen and Twaalfhoven 2001). The relatively long-term effects of dam reoperation, the outcomes and impacts, were not covered in this study because the focus is on understanding how dam reoperation for e-flows occurs and not on the after effects of dam reoperation. These outcomes of dam releases on downstream ecology have been the focus of several papers already (e.g., Gillespie et al. 2015; Olden et al. 2014; Thompson et al. 2018).

The Who, What, and Why of Dam Reoperation for E-Flows

In addition to using the logic model framework to understand how dams are reoperated, the stakeholders involved in the process (who), the motivation for e-flows release (why), and the original purpose of the dams (what) were investigated. The elements compared under each of these variables were informed by literature on dam reoperation and e-flows. For instance, for the stakeholders involved, the elements compared comprised stakeholder groups typically mentioned as forming part of e-flows studies and assessments in the literature. These include national, regional, and local government agencies, dam operators, and nongovernmental organizations (NGOs), among others. The option of indicating additional elements, such as new stakeholder groups not identified by the authors, was covered by providing survey respondents with the option to select "Other" in answer to the relevant survey question and then fill in a bespoke answer.

Hurdles to Dam Reoperation

The hurdles to the process of dam reoperation were identified through open-ended questions on what main hurdles were encountered in the process, when these hurdles were encountered, and what was done in an effort to overcome these hurdles. The open-ended question type was used here to elicit maximum information so that nuances that could be lost in closed-ended questions could be captured for analysis.

Data Collection: Survey

Survey Setup and Administration

The target participants in the survey were dam operators, water managers, researchers, and other resource persons who have been involved first-hand in e-flows implementation through dam reoperation across the world. The initial list of potential survey respondents was derived from three sources, namely

- authors of scientific papers on e-flows identified through the systematic literature review of Owusu et al. (2021b),
- the existing network of the authors of the present study, and
- the European training and research network for environmental flow management in river basins (EuroFLOW) project network, of which this study forms part.

From the initial list, recommendations as well as introductions to other potential survey respondents who have been involved first-hand in dam reoperation projects were also sought. Additionally, as part of the survey itself, respondents were asked if they could identify people in their network who were familiar with dam reoperation and these people were then included as potential respondents. In total, the survey was sent to 109 experts and remained active for a period of 6 weeks beginning November 12, 2019. The nonrandom convenience sampling approach taken in this study was necessitated by the criteria that survey respondents must have first-hand experience in dam reoperation for e-flows and also to expedite data collection. The disadvantage of this is the reduction in the power of statistical analysis and introduction of bias due to the overrepresentation of one or more subgroups (Smith 1983).

The self-administered structured internet survey (a copy is given in the Supplemental Materials) was developed using qualtrics. XM software (Qualtrics 2019b). An important consideration in designing the survey was to keep the time required for completion to a minimum, ideally under 15 min, to limit participant fatigue (Creswell and Creswell 2018). A mix of closed-ended and open-ended questions was adopted, the former to ensure that a minimum input was received from each respondent because the closed-ended questions are easiest to answer, and the latter to draw out additional insights that are unique to the specific cases. Respondents were also given the option of repeating the survey for a second case of dam reoperation if they had been involved in more than one case. The survey was pretested by two resource persons to evaluate the length of time required for completion and also to improve on the structure, instructions, and content of the survey. This led to minor modifications and improvement of the instructions to respondents.

A three-phase process over a period of 4 weeks was followed in administering the survey (Salant and Dillman 1994;). An advance notice of the survey was sent out a week before the actual survey to the respondents identified through the researchers' network. For those in the EuroFLOW network, an advance notice was placed in the monthly newsletter. The second email contained the actual survey sent via qualtrics.XM. This was followed 1 week later by a short reminder to the nonrespondents.

Ethical Considerations

The choice of qualtrics.XM as the survey tool was informed by the fact that it is General Data Protection Regulation (GDPR) [Regulation (EU) 2016/679–General Data Protection Regulation] compliant and allows for anonymization such that responses are not associated with any personal data, location, or IP address (Qualtrics 2019a). Furthermore, data collected using qualtrics.XM are completely owned and controlled by the creator of the survey (Qualtrics 2019a). These attributes of qualtrics.XM fit within the data management plan created by the researchers to protect the privacy of respondents. The data management plan and the overall survey protocol was approved by the Human Research Ethics Committee (HREC) of the Delft University of Technology in the Netherlands (Delft University of Technology 2009).

Data Cleaning

In line with the survey protocol adopted, referrals and any information that gave away identities or were deemed sensitive, particularly in response to open questions, were anonymized. The coordinates for the dams were identified, and background research was carried out on each dam to validate their classification as either successful or stalled. In the cases where one dam was reported on multiple times, these were consolidated and inconsistencies corrected based on available literature.

Data Analysis

Tests of Independence

The survey results were organized into two groups: successful cases of dam reoperation and stalled cases of reoperation. To detect any distinguishing characteristic between the two groups of cases, a statistical test of independence was carried out on the inputs, activities, and output of dam reoperation, as well as the original purpose of dam, motivation for e-flows, and the stakeholders involved in the process of dam reoperation. The comparison between the two groups of cases was undertaken using Fisher's Exact Test (Fisher 1925) and then validated using Barnard's Exact Test (Barnard 1945). Both tests are nonparametric tests of independence for two nominal variables with small sample sizes. Fisher's Exact Test, the more popular test, assumes that the row and column totals are conditioned, thus making it conservative when either one is unconditioned, as is the case in this study (Mehta and Hilton 1993). However, the improvement in power is small using other alternative tests, such as Barnard's Exact Test (McDonald 2014). The debate on which exact test is most appropriate persists. In this study, the equality of the probabilities of successful and stalled dam reoperation are calculated and presented for both tests (Table 1), but the primary interpretation is undertaken using Fisher's test because it is the more conservative test with results that are more intuitively understood.

The null hypothesis for Fisher's and Barnard's tests (H_0) is that there is no difference between the relative proportions of two variables. This will be rejected in favor of the alternative hypothesis (H_1) that the probability of successful or stalled dam reoperation differs significantly depending on the approach taken to dam reoperation, if a two-tailed p-value ≥ 0.05 is returned by both tests with a 95% confidence interval that excludes the null value of 1 for odds ratios. The two-sided p-value is used because the direction in which a given approach impacts the outcome of dam reoperation is unknown (McDonald 2014).

In this study, the Bonferroni correction (Bonferroni 1936) was applied as a correction for the multiple comparisons undertaken. The goal of such corrections is to reduce the number of false positives (i.e., the rejection of the null hypothesis when it is in fact true) when a large number of statistical tests are carried out, but on the other hand these correction factors have the disadvantage of increasing the number of false negatives (Rothman 1990; Perneger 1998; Nakagawa 2004; McDonald 2014). As such, any statistically significant variables found before application of the multiple comparisons correction factor in this study are also highlighted for discussion.

Qualitative Analysis

To analyze the hurdles encountered, the time they occurred, and the approaches taken in overcoming them, a content analysis was carried out on the responses received to the open-ended questions by a single coder. First, a broad categorization of the responses received to each question was carried out. This was an inductive, response-level categorization carried out manually to identify the major themes in each response. This was followed by a comparison of the categories in the successful and stalled reoperation cases.

Results

The findings from the survey are presented in this section, beginning with a profile of the respondents and the dams elaborated on. This is followed by results of the statistical tests of independence and then by the qualitative analysis of the hurdles encountered in the groups of cases of successful and stalled dam reoperation.

Profile of the Respondents

A total of 25 completed surveys, covering 25 unique cases, were returned at the close of the survey period, representing a relatively high (23%) survey return rate (Owusu et al. 2020). Although two of the respondents reported on the same case, another respondent reported on two unique cases. The majority of the respondents were scientists, but two respondents were civil society advocates and one a dam operator. An overview of the expertise of the survey respondents, specifically, their years of experience in water resources management, cases of dam reoperation they have worked on, and the number of unique river systems that these cases consider is shown in Fig. 1.

An analysis of the survey respondents by their experience shows that over 60% have more than 10 years of practical experience in the field of water management. Their wide-ranging experience is

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Table 1. Results of Fisher's and Barnard's Exact Tests (2 significant figures) ($n = 25$)

Variable category	Variables	Elements	Fisher's Exact Test *p*-value	Fisher's Exact Test 95% confidence interval		Fisher's Exact Test Odds ratio	Barnard's Test Statistic	Barnard's Test *p*-value	Barnard's Test Nuisance parameter
How	Inputs	**Legislation**	**0.015**	**1.2**	**130**	**9.8**	**−2.6**	**0.011**	**0.44**
		Scientific studies	**0.015**	**0.0074**	**0.80**	**0.10**	**2.6**	**0.011**	**0.44**
		Natural trigger	1.0	0.023	∞	∞	−0.98	0.064	0.53
		Requests							
		Human-made trigger	0.48	0.18	∞	∞	−1.4	0.21	0.11
		Planned upgrade							
		Other	0.073	0.0023	1.5	0.13	2.0	0.053	0.25
	Activities	Legislation	0.48	0.18	∞	∞	−1.4	0.21	0.11
		Flow experiments	**0.0017**	**2.6**	∞	∞	**−3.3**	**0.00099**	**0.50**
		Workshops	0.38	0.29	36	2.6	−1.1	0.35	0.91
		Scientific studies	0.645	0.17	26	1.8	−0.60	0.61	0.90
		Physical modification	0.22	0.40	∞	∞	−1.8	0.11	0.50
		Modeling	1.0	0.19	7.7	1.2	−0.23	0.83	0.35
		Other	0.48	0	36	0	1.06	0.35	0.084
	Flow target (output)	Minimum flow	1.0	0.18	8.9	1.2	−0.27	0.81	0.27
		High flow	0.38	0.36	39	3.0	−1.2	0.24	0.30
		Flood releases	0.59	0.21	190	3.2	−1.0	0.40	0.14
		Entire flow regime	0.70	0.10	4.0	0.64	0.58	0.65	0.50
		Ramping rates	0.48	0.18	∞	∞	−1.4	0.21	0.11
		Other	1.0	0.011	78	0.92	0.059	1.0	0.50
What	Original purpose	Flood control	1.0	0.14	21	1.5	−0.40	0.76	0.17
		Hydropower	0.41	0.33	20	2.3	−1.0	0.40	0.85
		Irrigation	1.0	0.18	8.9	1.2	−0.27	0.81	0.27
		Navigation	0.48	0.18	∞	∞	−1.4	0.21	0.11
		Recreation	1.0	0.011	78	0.92	0.059	1.0	0.50
		Water supply	1.0	0.13	5.3	0.84	0.23	0.83	0.68
		Other	1.0	0.024	∞	∞	−0.98	0.53	0.064
Why	Motivation	Habitat protection	1.0	0.067	18	1.1	−0.09	0.10	0.50
		Commercial resource	1.0	0.089	130	2.0	−0.54	0.71	0.13
		Endangered species	1.0	0.024	∞	∞	−0.98	0.53	0.06
		Scientific knowledge	0.38	0.028	3.4	0.38	1.1	0.35	0.089
		Other	0.073	0.79	470	8.6	−2.1	0.044	0.47
Who	Stakeholders	National agencies	0.38	0.29	36	2.6	−1.1	0.35	0.91
		Regional agencies	0.11	0.64	39	4.4	−1.8	0.088	0.40
		Local governmental agencies	1.0	0.13	5.3	0.84	0.23	0.83	0.68
		Dam operator	0.030	0.98	590	11	−2.4	0.021	0.71
		NGO	1.0	0.14	5.4	0.86	0.19	0.91	0.50
		Civil society groups	0.67	0.25	16	1.83	−0.72	0.28	0.064
		General public	**0.030**	**0.0016**	**0.93**	**0.087**	**2.4**	**0.016**	**0.50**
		Scientists	***0.00098***	***2.6***	***1,700***	***29***	***−3.4***	***0.00060***	***0.50***
		Other	0.67	0.25	16	1.8	−0.72	0.53	0.064

Note: Statistically significant results after applying Bonferroni correction (p-value $= 0.0012$) are in bold italics, and statistically significant results without Bonferroni correction (p-value $= 0.05$) are in bold.

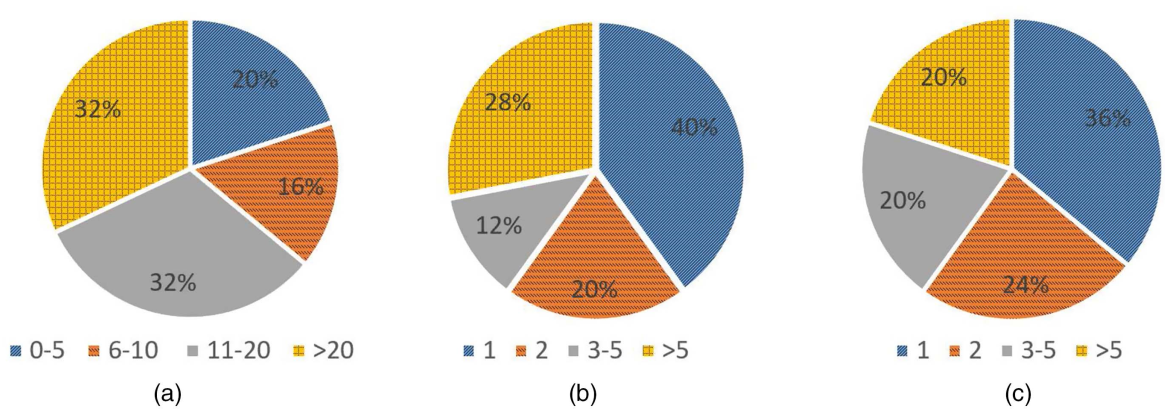

Fig. 1. Overview of respondent's expertise: (a) years of experience in water management of survey respondents; (b) cases of dam reoperation respondents have worked on; and (c) different river systems covered in the cases of dam reoperation.

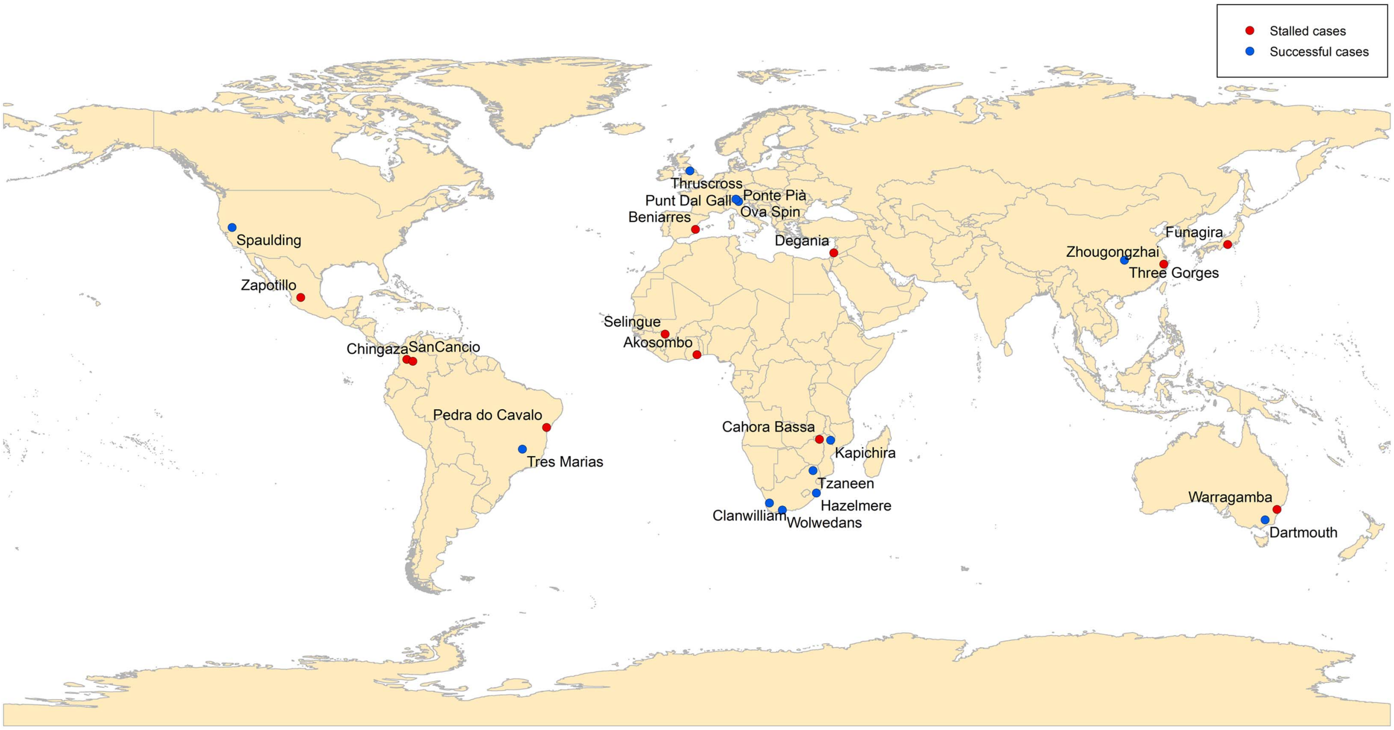

Fig. 2. Names and locations of the dams reported on in the cases of successful and stalled dam reoperation identified and elaborated by survey respondents.

also borne out in the map of the cases considered, with at least one case each of successful and stalled dam reoperation in all six continents with dams (Fig. 2).

Dam Reoperation Cases

Fig. 2 shows the location and names of dams elaborated on by the respondents. These dams included 13 successful cases and 12 stalled cases of dam reoperation. In previous literature reviews, primarily cases from Europe, southern Africa, and Australia were reported (Olden et al. 2014; Owusu et al. 2021b). This survey managed to obtain information on cases on all continents, notably in South America as well, which may have been underrepresented in previous studies due to language differences.

Comparison of Approaches to Successful and Stalled Dam Reoperation

Test of Independence

The results of the tests of independence using Fisher's and Barnard's exact tests are presented in Table 1. With 41 comparisons, applying the Bonferroni correction results in a p-value of 0.0012. The significant difference between stalled and successful dam reoperation attempts lies in the involvement of scientists. Before correction for multiple comparisons however, the results also point to a difference between successful and stalled cases of dam reoperation when it comes to having legislation and a scientific research base as Inputs to the process; undertaking flow experiments as an Activity; and the inclusion the general public as stakeholders in the process. These are therefore areas that should be further investigated. It's worth noting that the results of Barnard's exact test are consistent with those of Fisher's except on whether flow experiments are undertaken as an activity in dam reoperation.

Using the significant test result for Scientists under Stakeholders as an illustration, the Fisher Exact Test result is interpreted as follows: the success rate of dam reoperation is statistically significantly related to having scientists as stakeholders in the process, with the odds of scientists as stakeholders being 2.6 to 1,700 times higher for successful cases than stalled cases. For the sample of dams identified in this survey, the probability of scientists as stakeholders in the process of reoperation is over 29 times higher for the successfully reoperated dams than for stalled cases of reoperation identified by respondents. For odds ratios less than 1, it is more easily understood using the multiplicative inverse of the odds ratio, which is then interpreted as the odds of stalled reoperation to successful dam reoperation.

Hurdles to Dam Reoperation

The types of hurdles encountered in the process of reoperation are shown in Fig. 3. The main hurdles were placed into four groups after content analysis of the responses to open questions on hurdles faced during dam reoperation: technical or science-related hurdles, hurdles to do with the stakeholder network involved in the process of dam reoperation, policy-related hurdles, and finally, hurdles arising from physical constraints in available water or infrastructure resulting in a high economic trade-off between e-flows and traditional water uses. Examples of the hurdles that fall into the four categories are given in Table 2.

In the case of successful reoperation, the approaches taken to overcome the main hurdles are shown in Fig. 4, and the attempted solutions in the case of stalled reoperation are presented in Fig. 5. Once again, the categories of approaches for both successful and stalled reoperation were created based on the responses to an open-ended question. It can be seen that cases of successful and stalled dam reoperation have two approaches to overcome hurdles in common. These are (1) consultations or negotiations between stakeholders, and (2) scientific studies. Although consultations were

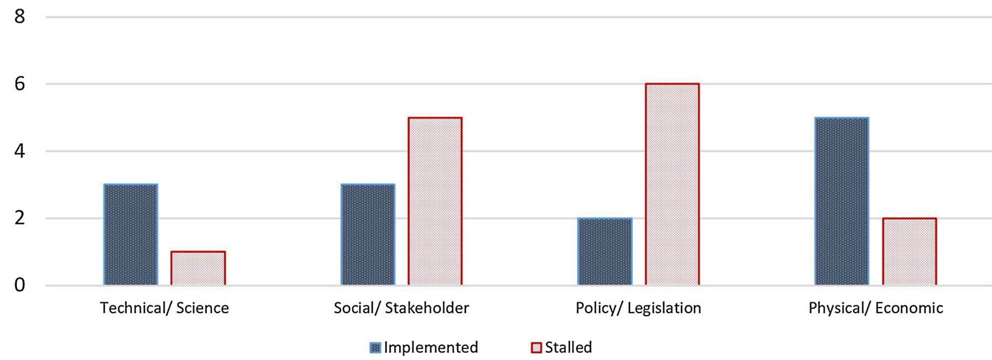

Fig. 3. Types of hurdles encountered in successful and stalled cases of dam reoperation. In some stalled cases, two main hurdles were reported.

Table 2. Examples of the hurdles encountered for each of the four main categories of hurdles to dam reoperation for e-flows implementation

Categories of hurdles identified	Example of hurdles in each category
Technical/science	Lack of data; challenges in translating e-flow requirements into practical dam releases
Social/stakeholder	Extended discussions or negotiations; pushback from key stakeholders; lack of interest of some stakeholders; change in personnel
Policy/legislation	Lack of supporting legislation; no political will; externally funded or backed project with little local support
Physical/economic	Not enough water; reduced revenue; interactions with other dams; possible damage to dam

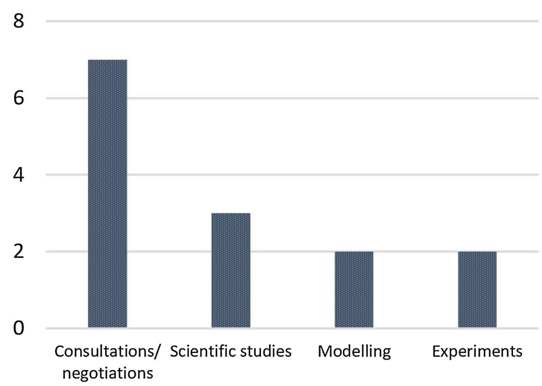

Fig. 4. How the main hurdles were overcome in cases of successful reoperation. In some cases, more than one approach was adopted to overcome the main hurdle.

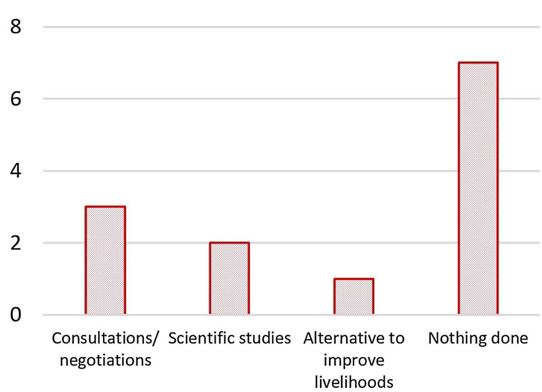

Fig. 5. Attempts made to overcome hurdles in stalled dam reoperation cases. In some cases, more than one approach was adopted to overcome the main hurdle.

the most common approach in overcoming the main hurdles in successfully reoperated dams, in 7 out of 13 stalled cases of dam reoperation, nothing was even attempted to overcome the main hurdle, and the process came to a halt.

Regarding when the main hurdle to dam reoperation was encountered once the process began, in all but 1 of the 13 cases of successful reoperation, the responses were "immediately," "at the start," or "from the beginning," implying that there was an awareness of the challenges to be overcome right from the beginning of the process. As such, all activities could be tailored to overcoming that hurdle at the outset, thereby increasing the likelihood of a successful outcome. In contrast, in half of the stalled cases, a period of 1 year to a maximum of 4 years went by before the main hurdle to dam reoperation was encountered.

Discussion

Each case of dam reoperation for the release of e-flows occurs in a unique social and environmental context. Even so, by comparing cases of successfully reoperated dams with stalled attempts of dam reoperation from different geographic locations with varying biophysical as well as socioeconomic conditions, it is possible to identify characteristics that transcend the local context of each case to identify what distinguishes the two groups from one another (Baskerville and Lee 1999). Considering the small number of survey responses, however, the observed trends are not interpreted rigidly but can be considered as hypotheses for further study. These are discussed in this section using evidence from literature.

It is found that the original purpose for which a dam was built, the motivation for implementing e-flows, and the target of flow manipulation in providing e-flows are similar for both groups and have no significant bearing on the outcome of dam reoperation. The key difference lies in the stakeholders involved, especially the involvement of scientists, who increase the odds of successful dam reoperation. Other differences worth highlighting for future investigation lie in the drivers (i.e., Inputs) and the Activities in the process of dam reoperation. The odds of a successful outcome are potentially higher when legislation is an input to the process, but the odds of the process stalling appear higher when scientific studies are an Input.

At first glance, the fact that having scientific studies as an Input has the potential to reduce the odds of dam reoperation may seem peculiar—more so because it seems to contradict the fact that scientists are important stakeholders whose involvement significantly improve the odds of success. However, there is a subtle interpretation. It is not science itself but its positioning in the process of dam reoperation that makes it an enabling or hindering factor, i.e., whether science engages in a dogmatic manner to promote and push e-flows or adopts a more egalitarian manner and facilitating role to support the reoperation process.

In research on pilot projects in water management, Vreugdenhil et al. (2010) referred to the positioning of science as the "knowledge orientation" and identified two models: the communicative model and the expert-driven model. In the communicative model, local stakeholder knowledge is central, with expert knowledge forming a complement (Vreugdenhil et al. 2010). In contrast, there is the expert-driven model, where priorities, knowledge, and solutions are defined and prepared by "experts" with a focus on technical and biophysical impacts (Dosi 1988; Vreugdenhil et al. 2010). This orientation is perfectly captured in a comment by one respondent regarding a stalled case: "Too much [of] an outside approach by environmental NGOs trying to provide evidence for the justification of an e-flow approach using studies." Indeed, Richter et al. (2006), in their work on the Sustainable Rivers Project, promoted the ideal of the communicative model because this fosters ownership of the process and a commitment to see e-flows implemented. Based on over 25 years of experience in the e-flows field, O'Keeffe (2018) also identified the need for "local champions" as essential for successful training and implementation of e-flows.

In line with the positioning of science argument, where the general public is involved in the dam reoperation process, the tests for independence suggest a reduced chance of success. Possible explanations of this phenomenon relate to the phase at which the general public became involved. As argued in the preceding paragraphs, in situations where experts, officials, or scientists have preconceived ideas and solutions and the general public are involved at a late stage, much resistance to the "solutions" can be encountered (Arnstein 1969; Cuppen 2012). Alternatively, a perfunctory or an unstructured stakeholder engagement process in which the general public is involved can lead to delays, confusion, and frustration (Tritter and McCallum 2006; Cuppen 2010). Fruitful stakeholder engagement requires careful design (D'Hont 2020).

The possible increase in the odds of success when legislation is an Input can be explained using the findings of Cosens and Chaffin (2016), who examined the role of law in the assertion of water rights by indigenous peoples in Australia. They found that although internal innovation and self-organization may exist with respect to water rights, legislation serves as a catalyst for the establishment of supporting institutions, and even more importantly, legitimizes the activities and results of these institutions. In this light, legislation requiring or supporting e-flows enhances the chances of success of dam reoperation. It is also unsurprising that in half of the stalled cases, the major hurdle encountered was the absence of supporting legislation, manifesting as the absence of political will or local support.

The lack of legitimacy of groups attempting to implement e-flows is recognized as a stumbling block in some of the stalled cases. For example, with regard to the Selingue Dam in Mali, a respondent stated in response to a question on the efforts to overcome hurdles: "We are trying to establish an e-flow committee that has sufficient stakeholders and is politically embedded and is given the mandate to now run a full-fledged e-flow process." E-flows legislation may come at different levels, as found by Owusu et al. (2021b); however, in the majority of successful cases where legislation was an input to the process, local- or basin-level legislation, which is more in tune with local needs, existed. This should, however, not discount the fact that regional-level legislation like the Water Framework Directive in the European Union is also helping to push the e-flows agenda to the fore in member countries (Acreman et al. 2009; Acreman and Ferguson 2010).

Finally, in considering how the Inputs to dam reoperation influence the outcome, one might interpret the potential of legislation as an Input to increase the odds of success as proof that the top-down approach works in the process of dam reoperation. On the other hand, the fact that scientific studies as an Input appears to decrease the odds of success may be interpreted as showing the opposite; that bottom-up approaches are needed for successful dam reoperation. It can be argued that a combination of the two approaches is needed, so that there is a response from the bottom to top-down approaches and vice versa (Keare 2001). As such, e-flows legislation and policy may serve to provide an enabling environment for e-flows implementation, and scientific studies developed and carried out with local stakeholder participation provide the bottom-up information and commitment necessary to success (Bryant 1997; Keare 2001; Vreugdenhil et al. 2010; Tevapitak and Helmsing 2019).

This bottom-up–top-down interaction could apply to water allocation optimization where preferably, end-users are involved in the development of models as opposed to just being the recipients of finished products (Horne et al. 2016). The importance of this interaction also extends to other fields and is cited as one of three interrelated reasons for deadlock in the transfer of the Dutch Delta Approach to other countries (Minkman et al. 2019). Bolten's (2009) analysis of postwar efforts at rebuilding the agricultural sector in Sierra Leonne also addressed this disconnect between the government and international nongovernmental organizations (INGO) on the one hand and local people on the other as a reason for the standstill in postwar development.

The activities carried out by both successful and stalled cases of dam reoperation are very similar. The exception seems to be flow experiments: in the sample of dams in this study, none of the cases of stalled reoperation had implemented flow experiments compared with 8 out of 13 successfully reoperated cases. It is hypothesized that this stems from the fact that flow experiments require a high level of collaboration and consensus to set up and also require the buy-in of institutions with the power to change, albeit temporarily, the operation policy of the dam in question (Robinson and Uehlinger 2003; Kubly 2009; Warner et al. 2014).

An examination of the major hurdles that eventually caused the process of dam reoperation to halt in the stalled cases reveals that the political will and/or the stakeholder consensus required was absent in nine different stalled cases (Fig. 3 and Table 2). This is in line with the experience of O'Keeffe (2018), who identified challenges associated with entrenched positions of stakeholders as the most frequent and intractable cause of the suspension of e-flow initiatives. The absence of stakeholder consensus and commitment may also account for the fact that hurdles were identified relatively late in the process of dam reoperation in stalled cases compared with successful cases, and also why in more than half of stalled cases, nothing was done when the major hurdle to dam reoperation was encountered. These would suggest that in the stalled cases, the three dynamics necessary for collaborative governance as framed by Emerson and Nabatchi (2015), namely principled engagement, shared motivation, and the capacity for joint action, were absent so that stakeholders could not reach consensus on dam reoperation.

In contrast, the most frequent hurdles in successful dam reoperation had to do with physical constraints to releasing environmental flows given the design of the dam itself and the surrounding infrastructure, or with inadequate water to satisfy e-flow requirements and other users. Faced with these hurdles, negotiations and consultations between stakeholders were the go-to strategy, despite the fact that hurdles specifically related to stakeholders occurred only in three successful cases. This is in line with findings from Beierle (2002) on stakeholder-based decisions, where joint fact finding was noted as important to conflict resolution. It is acknowledged that although consensus is a worthy pursuit, it should not come at the expense of the strategic interest of stakeholders, particularly disadvantaged groups (Manzungu 2002).

However, collaborative governance does improve ecological outcomes (Scott 2015; Ulibarri 2015) and a consensus on water allocation must be reached for dam reoperation to occur. As set forth by Richter et al. (2006, p. 301), a key point of emphasis among stakeholders to encourage consensus should be "by keeping the whole system healthy, each part of the system should benefit." Ultimately, the reality of reaching a consensus to release e-flows in the long term may be that in extremely dry years other water users take precedence. In the words of one of the respondents in a successful case, "Every time we have a drought we do not have e-flows."

It is important to note that the findings of this study are based on a sample size of 25 dams following a nonrandom convenience sampling. This relatively small sample size implies that small or even moderate effects are hard to detect, and the sampling approach also resulted in the overrepresentation of scientists (Little 1989; McDonald 2014; Morgan 2017). As such, it is recommended that further studies featuring larger databases of dams or perhaps more detailed case studies are important to fully investigate the impasse narrative in dam reoperation to accommodate e-flows.

Conclusion

Using a self-administered structured internet survey, this study draws on first-hand practical experience of experts who have taken part in dam reoperation projects for e-flows implementation to identify the variables affecting its success. Differences related to who was involved in the process, what the original operation of the dam was, and why e-flows were desired were investigated in a number of cases of successful and stalled attempts to reoperate dams. On the question of how dam reoperation occurs, a logic model approach was used to distinguish among the drivers to the process, the activities undertaken to reach the goal of changing dam operations, and the output or flow change targeted. In addition, the hurdles encountered and the attempts made to overcome these hurdles were investigated. This study therefore fills an important knowledge gap because stalled cases of dam reoperation for the environment have not yet been reported in the scientific literature.

The results indicate that the difference between success and stalling lies mainly in the who of dam reoperation and to a lesser extent, the how. With respect to the stakeholders involved in the process, scientists increase the odds of success, whereas participation of the general public potentially decreases the odds of success. With respect to Inputs or drivers to the process, the odds of a successful dam reoperation appear higher when legislation is in place, but in contrast the odds are lowered when scientific studies drive the process. Furthermore, flow experiments are found to be the activity most associated with successful dam reoperation. Finally, the analysis of the hurdles encountered and how they were overcome reveals that a strong stakeholder network is important in achieving a successful outcome.

Based on these results, it is possible to propose a number of facilitating factors in reoperating dams for further investigation as follows:

- Scientists are important stakeholders in the process of dam reoperation, but should play a supportive role rather than drive the process.
- In undertaking scientific studies for determination of e-flows, a consensus on the priorities, knowledge gap, and solutions must be reached together with local stakeholders.
- Local-level legislation and policy on e-flows provide the enabling environment for dam reoperation for e-flows.
- Genuine, carefully designed consultations and negotiations between stakeholders can overcome hurdles encountered in the process of dam reoperation for e-flows implementation.

Finally, there is a dearth of information on individual cases of dam reoperation that have stalled and remain at an impasse. Future in-depth studies on these cases are needed to draw out the unique social and environmental contexts in which they occurred and how these contextual factors influenced the outcome. Such knowledge will serve as an additional resource for water managers and other stakeholders in future attempts to reoperate dams in diverse contexts.

Data Availability Statement

All data, models, or code generated or used during the study are available in a repository or online in accordance with funder data retention policies. [Owusu, A. G., Mul, M., van der Zaag, P., & Slinger, J. (2020). *Dataset-Global survey of environmental flow realization and dam re-operation*. Retrieved from https://doi.org/10.4121/uuid:0007a286-56d8-4f37-bf47-338738200c69.]

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Supplemental Materials

The structured internet survey is available online in the ASCE Library (www.ascelibrary.org).

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