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Transdisciplinary Research in Water Sustainability: What's in it for an Engaged Researcher-Stakeholder Community?

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ABSTRACT: This study uses semi-structured interviews and an online survey to explore the structure, challenges and outcomes of a five-year National Science Foundation-funded water scarcity modelling project in the Willamette River Basin of Oregon, USA. The research team chose to facilitate broader impacts by engaging stakeholders from the study's inception (e.g. developing grant proposal, study implementations, defining model run scenarios) through its completion and extension of findings. The team used various engagement formats (field trips, small and large group meetings) and encountered many challenges, including the lack of a shared vision, different professional languages, research complexities and project management. Through stakeholder engagement the team overcame challenges, facilitated learning, and improved and extended the research process and results. Participation in engagement events was positively correlated with beneficial broader impact outcomes. We compare these outcomes with NSF's five broader impact criteria: advance scientific discovery and understanding, broaden participation of underrepresented groups, enhance research infrastructure, broadly disseminate results, and benefit society. We show that stakeholder engagement is one method to achieve the five original NSF criteria and suggest that a sixth criterion can be achieved through stakeholder engagement – that of developing the research community.

KEYWORDS: Broader impacts, climate change, modelling, stakeholder engagement, Willamette River Valley

INTRODUCTION

In 1997 the United States National Science Foundation (NSF) established Intellectual Merit and Broader Impacts as two equal proposal-evaluation criteria, and produced a Broader Impacts guide (National Science Board, 2011) to evaluate proposals by asking, to what extent does the activity…

1. …advance discovery and understanding while promoting teaching, training, and learning?
2. …broaden participation of underrepresented groups?

3. …enhance the infrastructure for research and education, such as facilities, instrumentation, networks, and partnerships?
4. …broadly disseminate results to enhance scientific and technological understanding?
5. …benefit society?

Despite these directions, reviewers maintain that the Broader Impacts guidelines are not as clearly or consistently applied across projects and institutions as the Intellectual Merit criterion and are more difficult to assess (National Science Board, 2011). Researchers often enjoy participating in broader impact activities (Pearson et al., 1997) but struggle to engage diverse participants in creative ways. Only 65 percent of NSF-funded projects had broader impact statements, and among those, 19 percent included only one of five possible activity categories. Teaching/training was the most frequently utilised method, followed by broad dissemination of results (Nadkarni and Stasch, 2013). These are familiar methods that benefit academic researchers. However, the emergent paradigm implicit in the NSF proposal criteria creates an expectation that scientists and science stakeholders engage in research together for their *mutual* benefit (Frodeman et al., 2013).

This expectation coincides with those for natural resource management and policy to incorporate the 'best available science' (Lester et al., 2010) to address problems such as global climate change (Rayner et al., 2005), risks to biodiversity (Brainard et al., 2013) and water scarcity (Chang et al., 2014). However, environmental research is not well integrated into management and policies for a host of reasons, including uncertainty, conflicting priorities, institutional limitations, miscommunication or lack of effective communication, differing values and lack of locally relevant results (Rayner et al., 2005; Smith et al., 2009; Weible and Sabatier, 2009; Callahan et al., 2013; Gregory et al., 2013; Yang et al., 2013). To achieve broader impacts research must be credible, salient and legitimate (Cash et al., 2003). Transdisciplinary research, engaging stakeholders with researchers from multiple disciplines throughout the research process (National Research Council, 2006; Dilling and Lemos, 2011; Mackenzie et al., 2012), is one method that can produce such results.

Many previous cases offer lessons learned and the impacts resulting from the researcher-stakeholder engagement experience. These include establishing clear roles and responsibilities, being sensitive to stakeholder needs, engaging early, integrating quantitative and qualitative knowledge, making use of existing networks and allocating resources so as to improve relationships between participants and improve research credibility (reviewed in Ferguson, 2016). Most case assessments are personal reflections made by the researchers after specific engagement events or are from cases exploring participatory management and decision-making tools leading to immediate decisions. While these studies provide many helpful examples of the way in which public engagement can influence project outcomes there is a lack of research that analyses the participation process itself as perceived and experienced by the participants.

We sought to address this knowledge gap in the researcher-stakeholder engagement process by characterising the experiences and perceptions of all the participants and providing evidence for the impacts of participating in such a process. First, we characterised the structure of the researcher-stakeholder engagement process and then asked: (a) what challenges the research project and stakeholder engagement process encountered; and, (b) what the researcher-stakeholder engagement process achieved. This study explores barriers and pathways to success, includes recommendations to improve natural resource researcher-stakeholder engagement and identifies an emerging broader impact criterion: develop the research community.

METHODS

This study provides a case-study analysis (Berg and Lune, 2012) of one natural resource researcher-stakeholder engagement process – the Willamette Water 2100 (WW2100) project. WW2100 seeks to predict when and where water scarcity might occur in the Willamette Valley, Oregon, USA, up to the year 2100 as a result of climate change, population growth and water-use decisions. The Willamette River Basin is the largest river basin in Oregon, is home to approximately 70 percent of the state's population and supports critical runs of salmonid fish, vibrant industries, diverse agriculture, forestry and recreation. The Willamette River Basin is abundant in water resources, discharging approximately 27 million acre-feet of water annually to the Columbia River (Bastasch, 2006). However, water demand in the Willamette basin is inversely related to precipitation, creating a potential for conflict among competing water users in the event of future scarcity. For example, maintaining stream temperature for salmonids will reduce water levels in reservoirs, limiting access for boat enthusiasts.

To understand the trade-offs and complex socio-ecological system dynamics, 26 principal investigators, representing multiple disciplines, collaborated to integrate sub-models of the Willamette watershed processes. Hydrology, ecological engineering, climate science, applied economics, environmental engineering, water resources, forest ecology, fish and wildlife, and law dynamics interacted in one modelling framework called *Envision*. In addition to forming an interdisciplinary team, WW2100 engaged with approximately 215 water stakeholders representing state and federal agencies, policymaking groups, nongovernmental organisations and private industry throughout the research process. This case exemplifies a transdisciplinary research project that engages stakeholders to create usable science and achieve broader impacts.

An exploratory, sequential, mixed-methods approach was used to analyse the WW2100 case (Creswell, 2003). First, semi-structured interviews were conducted to develop an understanding of the views of key researcher-stakeholder engagement process participants. Then, a survey of all participants in the researcher-stakeholder engagement process was conducted to provide a quantitative assessment of participant perceptions of the process.

Semi-structured interviews

In the final year of the researcher-stakeholder engagement process 26 semi-structured interviews were conducted. Interviewees were purposively selected (Patton, 2002) based on their participation in the process and representativeness of various kinds of expertise. Participants who attended more events, or who represented a perspective not yet recorded, were asked for interviews and 12 stakeholders[1] and 14 research team members agreed (see Ferguson, 2015).

Interviews were conducted in person, via Skype or over the telephone between January and March 2015. Each interview followed a semi-structured interview guide (Ferguson, 2015), with questions prompting reflection on the process. Interview length averaged 55 minutes (range: 26-89 minutes). Interviews were digitally audio recorded and transcribed using *Express Scribe Transcription* software. The resulting transcripts were sent to interviewees for 'member checking' (Miles et al., 2014) to ensure transcription accuracy. Transcripts were then analysed through an open coding process, facilitated by the computer software *MaxQDA* (Auerbach and Silverstein, 2003). An inter-coder reliability assessment (Creswell, 2003; Ryan and Bernard, 2003) of four researchers resulted in at least 90 percent concurrence, affirming theme reliability.

Online survey

The quantitative phase used a census design to survey all members of the WW2100 mailing list. Participants were invited via e-mail to complete an online questionnaire administered using the

[1] Stakeholders interviewed include a tribal representative, farmer, water utility manager, state agricultural and water agency representatives, private technology industry representative, federal reservoir operations and forestry representatives, an irrigation district manager, city water agency representative, and a county government representative.

Qualtrics Survey System. Of 281 subjects invited, 45 research team members and 92 stakeholders[2] (total = 137) responded, for a 49 percent response rate. Average weekly survey return items did not change over time, and, given the response rate, conclusions about the WW2100 participant population can be inferred with 90 percent confidence (Creswell, 2003; Vaske, 2008). The online questionnaire was developed based on a preliminary content analysis of the semi-structured interviews. Respondents reported their participation in WW2100 and their perceptions of its outcomes. We used SPSS 22 statistical analysis software to conduct nonparametric analyses of the data.

Several indices were calculated from survey responses and used in later analyses. Indices for model utility, process utility, feeling heard, model understanding and overall participation were assessed for reliability using Cronbach alpha reliability analysis (Table 1, Table 2). Spearman rho (r_s) correlations then assessed the relationship between overall participation and these indices. In all analyses statistical significance was tested at a 0.05 level.

Table 1. Cronbach alpha reliability analyses for participation indices.

	Mean (M)[1]	Std. dev. (SD)[1]	Item Total Correlation	Alpha (α) if deleted	Cronbach alpha (α)
Participation Communication[a]					.83
Emailed a research team member	3.58	2.14	.74	.76	
Emailed a stakeholder	2.53	1.45	.60	.80	
Spoke to a research team member	4.00	2.07	.73	.76	
Spoke to a stakeholder	3.08	1.48	.40	.85	
Visited the WW2100 website	3.13	1.51	.71	.77	
Participation overall[b]					.66
Years of participation	0.04	.98	.34	.65	
Event participation	.10	1.01	.44	.59	
Seminar participation	.08	1.02	.53	.52	
Participation communication	.12	.97	.44	.59	

[1] Means and standard deviations are measured on scales as indicated by the corresponding letter superscripts.

[a] Means and standard deviations are measured on an 8-point frequency scale from 1 'Never' to 8 'Daily'. The mean values centre around 3 '2-3 times a year'.

[b] Means and standard deviations are standardised z scores.

RESULTS

Researcher-stakeholder engagement process structure

WW2100 engaged researchers and stakeholders from beginning to end. A small group of principal investigators formed the Broader Impacts Team (BIT) to facilitate stakeholder engagement and used various formats to connect researchers with stakeholders. Interviewees outlined the different engagement stages as they perceived them and emphasised the important role of the BIT in researcher-stakeholder engagement success. The BIT provided a forum for researcher-stakeholder interaction by

[2] Survey respondents self-identified as water resource planners, engineers, regulators and policy staff, as well as policy makers, fishery biologists, hydrologists, water utility managers, educators, agricultural industry representatives, environmental NGO staff or other.

Table 2. Cronbach alpha reliability analyses for model utility, process utility, feeling heard and model understanding indices

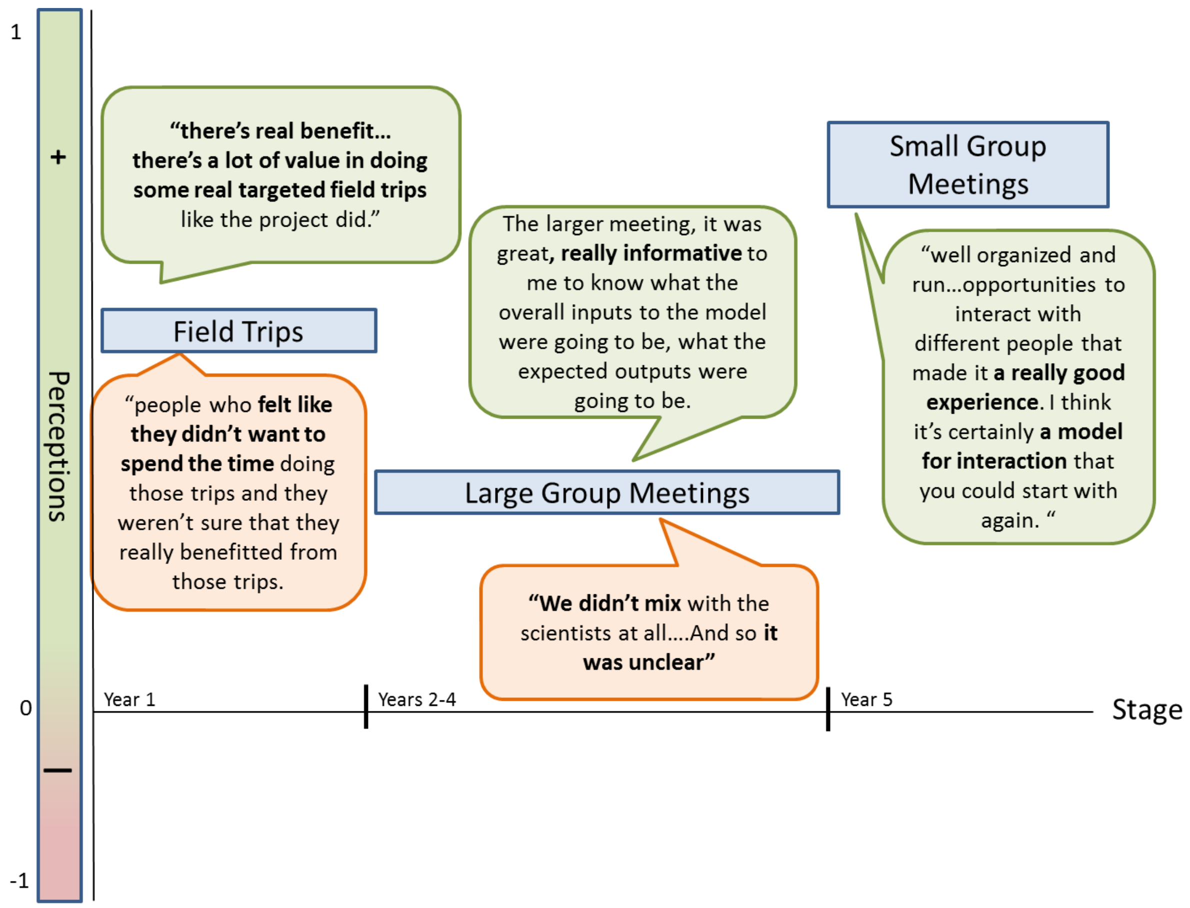
	Mean (M)[1]	Std. dev. (SD)[1]	Item Total Correlation	Alpha (α) if deleted	Cronbach alpha (α)
Perceived model utility					.91
The Envision model informs resource managers	3.54	.74	.84	.88	
The Envision model informs policy makers	3.56	.74	.82	.89	
The Envision model informs water users	3.52	.79	.77	.89	
The Envision model adequately depicts water use and scarcity in the Willamette Valley	3.29	.76	.72	.90	
The Envision model contributes to scientific knowledge	3.82	.77	.71	.90	
Gained a broader view of water in the Willamette Valley	3.99	.84	.65	.91	
Perceived process utility					.88
I understand the perspectives of diverse water users in the Willamette Valley	3.90	.75	.68	.86	
I learned from research team members	4.03	.84	.75	.85	
I learned from stakeholders	3.92	.82	.73	.85	
I formed or strengthened relationships with research team members	3.44	.91	.65	.87	
I formed or strengthened relationships with stakeholders	3.31	.77	.62	.87	
I shared in a necessary discussion on water in the Willamette Valley	3.82	1.03	.74	.86	
Understanding of the Envision model					.90
I understand the Envision model's limitations	3.37	.88	.86	.82	
I understand the reasons for the Envision model's limitations	3.32	.89	.82	.86	
I understand what the Envision model can do	3.52	.85	.76	.91	
Participants felt heard					.82
Research team members respected my opinions during researcher-stakeholder engagement events	3.82	.76	.61	.79	
Stakeholders respected my opinions during researcher-stakeholder engagement events	3.78	.68	.64	.79	
Research team members learned from me	3.36	.89	.75	.75	
Stakeholders learned from me	3.34	.77	.62	.79	
My knowledge was incorporated into the Envision modelling tool	3.00	.85	.49	.83	

[1] Means and standard deviations are measured on a 5-point scale from 1 'Strongly Disagree' to 5 'Strongly Agree'.

planning and coordinating logistics for events and facilitated communication during and between official events. Process participants noted the importance of having a team devoted to stakeholder engagement for the project's success.

Throughout the project the BIT used different formats (field trips, large and small group meetings, e-mail and phone communications) for interaction to connect researchers and stakeholders. During the first year field trips and meetings held in the upper, mid and lower river basin introduced participants to the Willamette Basin and its multiple water sources and demands, and to one another. They also provided a shared experience from which to draw in future conversations. In years two to four annual large-group meetings provided a forum to continue the researcher-stakeholder conversation with research progress presentations and stakeholder feedback. A Technical Advisory Group (TAG) of 20-26 major water users and water policy and management stakeholders met as a small group in year five to vet researchers' modelling scenarios and create stakeholder-driven scenarios. Participants had varying perceptions of the formal activities' three stages (Figure 1). The activities, meeting components and participants' roles shifted with format. Interviewees found the facilitated sessions to be the most effective and valuable component of the process; however, various formats for engagement benefitted the project because "all three deliver different things".

Figure 1. Timeline of stakeholder engagement events (blue boxes) and positive and negative perceptions (green and red quotes, respectively) of these events.



Note: Location on the y-axis was determined by calculating the difference between positive and negative perception ratios drawn from interviews. A ratio/location nearer to 1 indicates that event was spoken of more positively than negatively by interviewed subjects.

Informal conversations and e-mails, meetings and telephone calls between participants resulting from the formal events further influenced the research in a tangible way. The BIT also produced outreach materials (newsletters, webinars and website) that maintained an 'e-connection' between the research and its stakeholders in between formal events. Stakeholders "appreciated the opportunity to do the webinars that have come out" but found themselves somewhat overwhelmed by the number of e-mails.

The BIT ensured that stakeholder engagement was prioritised throughout the process and that adequate time and resources were allocated for successful engagement activities, as described by one research team member, saying "the broader impacts team really made a lot of noise to make sure that this piece was integral in the project". Stakeholders also noted that the BIT organised events in such a way that stakeholders felt respected and valued to continue attending. "People start not wanting to show up if it's in a venue that's not nice. I just think this one was done right". One interviewee confirmed this important BIT role, saying, "If [BIT member] hadn't been involved, there would have been no public input at all".

Researcher-stakeholder engagement process challenges

Four types of challenge were identified for the WW2100 researcher-stakeholder engagement process: lack of a shared vision, interdisciplinary-related difficulties, research complexity and project management issues. Interviewees spoke of the possible causes of these challenges and gave examples of how the challenges manifested. Often they were overcome with effort from participants and project leadership.

By far "the biggest challenge [for WW2100] has been this lack of a shared vision in the project". Interviewees identified that participants had different research and stakeholder engagement philosophies, disciplinary traditions and experience with such projects. These elements combined with a conceptual, rather than detailed, proposal created multiple visions for WW2100. The presence of multiple participants with divergent visions for WW2100 occasionally led to conflicting actions. Researchers and stakeholders found it difficult to connect with one another. Researchers disagreed over when and how to involve stakeholders, what to do with stakeholder knowledge and how to reconcile stakeholder experiences with data from peer-reviewed literature. At times it appeared that the researchers were pursuing different research goals.

Research team members differed in their approaches to research from applied to theoretical science, from preferring quantitative to qualitative data and from a planning to a projection approach to alternative futures modelling. One research team member summarised the differences in this way:

> This Willamette Water 2100 (…) was a pretty serious unresolved collision between these two approaches in which the dominant designers of methodology came from, and insisted on, an academic hypothesis-testing single variable at a time changing approach and emphasised its strengths. Whereas the opportunities (…) to couple more tightly to what the stakeholders think is important requires that multiple assumptions, multiple parameters of the model change all at once (…) And that runs against the career commitments and frames of reference of traditional scientific approach.

The disagreement among research team members extended to the stakeholder engagement, as neither approach to research aligned with the stakeholder group's perspectives. One stakeholder noted how this challenge impacted the TAG in its mission: "It seemed to be kind of difficult sometimes to develop the scenarios, perhaps because the research team had different preconceived ideas than what the TAG members had".

Previous experience with interdisciplinary research and stakeholder engagement influenced researcher and stakeholder expectations for the engagement process. Researchers with previous experience working with stakeholders had a different idea for how the process would go than those who had never worked with stakeholders beyond general outreach.

> Some people came in with experience, having done it in the past on particular projects, and had an idea, but other people came from a really different point of view and set of experiences and so there was a long time of struggle (…) among the research team to figure out what was going to be acceptable for the stakeholder involvement process.

Disparate plans for the researcher-stakeholder engagement process were also traced back to the research proposal. Research team members stated that the proposal could have outlined the process more explicitly in the research plan rather than focusing on broad research goals. "At the very beginning [of the] project it was really quite unclear to me what we were exactly going to end up doing in the project".

Different visions for WW2100 caused conflict in the process, centring on when and how to involve stakeholders and their knowledge. Some participants preferred "early and often" stakeholder engagement, while others preferred to produce results first to "have something to talk about". There was resistance to stakeholder suggestions, in part because of a discrepancy in the feedback and model construction timeline.

> They started the process with all these workshops and giving presentations and (…) really had already done a lot of the work (…) and so when people ask you or tell you that all your assumptions are off they didn't really want to go back and redo all their work.

There was also debate over how to incorporate stakeholder knowledge into the model and the research. Should the stakeholders guide research questions, vet model assumptions, develop scenarios? Should this model incorporate stakeholder observations or rely on peer-reviewed literature for data? "There were academics who essentially were more convinced by peer-reviewed papers even if the data that went into them were national in scale and therefore of questionable relevance locally".

The project also required reconciliation over the research goal directions. Without a shared vision to guide a shared question, participants pursued individual questions for academic publications or regarding processes or scales beyond the scope of the project. This created conflict when participants discovered that WW2100 would not address their independently formed questions. One research team member discussed how forming a shared question in these cases can be elusive.

> You have to focus on questions that are scientifically interesting. So there's a Venn diagram. Society has certain questions they want answered, but not every question society wants answered is really going to make good science and so you have to try to find some overlap between those two. And it's a matter of luck and skill.

Research that integrates several areas of expertise brings with it the challenge (and opportunity) of diversity. In addition to different goals and philosophies, interdisciplinary researchers must meet the challenges of speaking different languages and working in large groups. "[It can be] long in duration because when you bring together this many disciplines you have to figure out how to talk to one another". Researchers and stakeholders from different backgrounds struggled to come to agreed meanings for apparently universal words. WW2100 required the reconciling of at least 12 glossaries. Many interviewees referred to the number of people involved in the project as posing a challenge. One researcher commented, "too many people and nobody took responsibility". The number of people and the number of languages presented transdisciplinary challenges for WW2100.

Participants noted that the spatial and temporal modelling extent was challenging to achieve and comprehend. Some questioned whether modelling the entire Willamette Basin was amenable to stakeholder engagement because there was not "enough connectivity and homogeneity and common purpose within the stakeholder group for them to function cohesively". Furthermore, modelling and imagining 85 years into the future was a challenge for many participants. "It took probably a couple meetings before (…) [we] started thinking that far out into the future. As a farmer businessman you definitely think into the future but I'm not sure that we think generations into the future".

The modelling process was also a complex challenge, with 13 interconnected sub-models and 21 future scenarios. "There is just a ridiculous huge amount of information that was trying to be put together and [that] (…) was just a Herculean challenge".

WW2100's scale brought basic project management challenges as well. Interpersonal relationships and planning logistics were cited as frequent challenges. One person stated plainly, "there were strong personality challenges". Managing personality differences required extensive effort and mediation within the project.

> I've had a lot of meetings with people to discuss differences of opinion, to work out agreements, (…) to encourage people to work together, to demand people work together, to plead that people work together, to provide resources to allow people to do things that will then help somebody else.

Merely organising the number of people involved in the WW2100 researcher-stakeholder engagement process was a logistical challenge for scheduling meetings. "They're busy; we're busy", as one interviewee stated. This led to an associated challenge of discontinuity from one meeting to the next. "The dynamic of any particular gathering changes a little bit depending upon who's there. And you can't have 100% attendance every time".

The lack of a shared vision, interdisciplinary challenges, modelling complexity and project management were the four types of challenge detailed by key WW2100 participants.

Researcher-stakeholder engagement process impacts

Interviewees identified, and survey respondents confirmed, a number of successes. Participants considered overcoming the aforementioned challenges a success. Interviewees voiced the research and stakeholder engagement successes of the project. Survey results indicate that participating in stakeholder engagement events was positively correlated with an individual's understanding and perception of the research results' utility, perception of feeling heard throughout the process and value for the stakeholder engagement process.

The project's most prominent success was associated with the research products, tools and publications. Half the interviewees celebrated WW2100's success in building a comprehensive Willamette Basin water model and were proud of the model they helped construct. "I feel quite confident saying (…) this is without a doubt the best look at water in the Willamette Valley that's ever been done". Many researchers and stakeholders were also glad that "there were papers published and written". By traditional research metrics, WW2100 was successful.

Individual participation in researcher-stakeholder engagement events was positively correlated with understanding (r_s = 0.42, p < 0.001) and perceiving the research results as valuable (r_s = 0.21, p = 0.002). Highly engaged participants understood the model and its limitations and felt that the model provided a broader view of water in the Willamette Valley while contributing to scientific knowledge and informing potential users. Engaging with research team members through model construction and scenario development led stakeholders to understand the results and how they might be useful. "This process was like wow (…) but it also helped us understand the tool more". Through their conversations, stakeholders and researchers could identify those questions that the tool could answer and how the answers might be used in the future.

Those who participated more in the engagement process expressed ways in which the results would be useful to scientific discovery and to water management and policy. The model contributes interesting results within each of its sub-models and was viewed as a means to inform future water-management projects and as a tool to facilitate planning discussions. One stakeholder shared her need for this project's results: "If we can have a visual representation of possible changes, things to consider (…) that's exactly what we need. Because it's very hard to visualise all these changes on the landscape (…) I think this could be a very powerful planning tool". Another stakeholder shared how the results could contribute to future discussions, saying: "It tells us the direction we need to go and (…) the issues we need to think about (…) It's a conversation starter. But if you don't do this analysis, it becomes a random conversation".

Individual participation also correlated positively with a perception of feeling heard in the WW2100 research project (r_s = 0.36, p < 0.001). Interviewees considered the stakeholder engagement process and incorporation of stakeholder input successful overall.

> My impression of how their input was received is that it was well received. The investigators were very interested in the input they were getting, sought to clarify what they were hearing and, based on the iterative manner of the gatherings, it was clear that they took in what was said and dialled those changes or recommendations in to the best of their ability.

When participants felt heard they also felt valued. "They seemed like they were accommodated and got to express their opinions and felt like they were valued in the process". When people feel valued they are more likely to continue participating and the benefits of participating in the researcher-stakeholder engagement process grow.

Participation in WW2100 also correlated positively with expressing greater value of the research-stakeholder engagement process (r_s = 0.39, p < 0.001). Participants valued this process as a way to form or strengthen relationships, to understand other water users, to share in a necessary conversation about water, and to personally grow through learning. The process was valuable because it allowed participants to explore key current and future water issues together. Participants enjoyed considering water in new ways and interacting with people with whom they do not normally interact. One interviewee stated that this was the most valuable outcome: "I would say that the discussions and the relationship-building have been more beneficial to me than the actual nitty gritty numbers that it produces".

Participants attending multiple events formed and strengthened networks and arrived at a better understanding of each other as Willamette Basin water users by sharing in conversation. An industry representative found common ground with farmers over their economic dependency on water. Utility managers better understood the trade-offs associated with reservoir operations. Researchers came to understand each other's disciplines, and both research team members and stakeholders developed a better sense of each other's priorities. One researcher commented on the benefit of engaging in conversations with stakeholders: "It was interesting from a learning perspective to hear from them what the management concerns are and then to think about the actual logistics of how we would try to do that".

Interviewees perceived the engagement process as valuable, leading water users, research team members and stakeholders to better understand one another. Such understanding would not have been possible without the process to facilitate necessary conversations about water in the Willamette Basin. More than half the interviewees commented on the value of engaging diverse perspectives in constructive dialogue through this process. They frequently commented on WW2100's success in attracting diverse attendance and how their presence enriched the event and the project outcomes. One person said: "We had 20-25 folks, all coming from different perspectives and having (…) thoughtful conversation. It's been a pleasure (…) working with the group of folks as the stakeholders". Another said: "Having that dialogue amongst the users was probably one of the most successful parts of the project".

Like all large research projects, the WW2100 project had major challenges to overcome as described above. Despite these challenges and obstacles, however, all interviewees expressed that the researcher-stakeholder engagement process was valuable as a learning opportunity. Through WW2100, the participating water professionals said they learned new perspectives about water in the Willamette Valley, how to work together and how they might work together in the future.

> I have no doubt that there [are] perspectives that people in the stakeholder group hold now that they didn't hold coming into this process – that they, in fact, have learned from others in the group. So I think there's been some success there.

Another interviewee said: "I'm learning (…) and that's always helpful, both personally and professionally".

Engaging researchers with stakeholders improved both groups' operations through reciprocity. Stakeholders informed the model and provided necessary feedback to the researchers. One researcher spoke of the benefit of stakeholder involvement in research: "I think it keeps us from doing silly things. It keeps us grounded in the real world".

Stakeholders provided information on their operations, estimates and perceptions of reality to inform the model. They also shared their research questions, data and observations with the research team. Stakeholder groups also benefitted from the researcher-stakeholder give and take. Some realised how their operations could improve to support academic research, and most were able to glean useful information from WW2100's results and conversations.

Finally, the WW2100 researcher-stakeholder engagement process directly contributed to building the model's credibility and training project ambassadors. These were not explicit goals of the process but resulted naturally, according to the participants interviewed. The process "created a lot more buy-in (…) from all the people at the table". One stakeholder explained:

> (…) you had stakeholders involved from the beginning that could see this process all the way through. That's good because otherwise we would've just gotten something at the end and not had any idea how it was developed or who was working on it or why they were asking these questions.

Through engagement participants had a better understanding of the research questions, the reasons they were asked, the answers and how the results were obtained. Interviewees were already extending WW2100's impacts at the time of this study and expressed an interest in helping disseminate the final results. One interviewee volunteered: "I would be more than happy to help roll out whatever it is to the key people". Others posited that they could be "ambassadors" or "a champion" and "take the output back" to their groups.

DISCUSSION

This study characterised the structure, challenges and successes of researcher-stakeholder engagement in social-ecological modelling research. WW2100 used diverse engagement process activities, encountered previously documented challenges and produced relevant broader impact outcomes. Additionally, WW2100 produced outcomes for a stakeholder-engagement process that have not been previously documented and leads us to suggest a sixth criterion for broader impact evaluation: developing the research community.

Challenges of transdisciplinary projects

Many of the challenges observed in WW2100 are reviewed in similar case studies (e.g. Lemos and Morehouse, 2006), several of which also provide suggestions for avoiding or overcoming such challenges (e.g. Lang et al., 2012). WW2100 shared challenges, such as confronting the lack of a shared vision, interdisciplinary challenges and project management, with other studies before it. Transdisciplinary natural resource studies must develop a shared frame for the issue being explored, questions to answer and how to answer them (Pahl-wostl et al., 2007). Without it there will be different plans for a project, distrust and conflict (Lang et al., 2012; Manring, 2014; Mostert et al., 2007). WW2100 encountered this as its greatest challenge for many of the same reasons as previous studies. Different experiences led researchers and stakeholders to ask different questions (Lemos and Morehouse, 2006). Research teams had varying degrees of openness to stakeholder input (Mostert et al., 2007; Pahl-wostl et al., 2007). To overcome this challenge stakeholder knowledge must be accepted as credible (Mackenzie et al., 2012) and the engaged group must meet early and often to develop a shared frame for research (Lynam et al., 2010).

WW2100 shares interdisciplinary challenges with previous studies in which there are greater differences in perspectives among scientists of different disciplines than between scientists and stakeholders (Fuller, 2011). The concept of 'science' and how it should be practised is understood differently among disciplines. Through time-intensive discussions WW2100 overcame its interdisciplinary language challenges to arrive at shared definitions of key terms, such as 'water scarcity' and 'stakeholder engagement'.

The WW2100 BIT encountered logistical challenges in organising researcher-stakeholder engagement activities over a five-year period. Although engaging with many was necessary for the large scope of the project (Mahmoud et al., 2009) it is time and resource intensive (Mackenzie et al., 2012; Mostert et al., 2007). Project management is an oft-overlooked transdisciplinary challenge. Project logistics become more challenging as the study area, number of researchers and number of stakeholders increase. Resources devoted to the project must increase accordingly.

One challenge that was absent from WW2100 that is present in other studies is political conflict that arises among stakeholders with competing water uses (Mianabadi et al., 2014; Mostert et al., 2007). WW2100 is a unique case among the many studies of stakeholder engagement in that it is driven strictly by research rather than management questions and evaluates water availability far into the future. There was no urgency to the research or the collaboration due to an impending water allocation decision. Moreover, the Willamette is a comparatively water-abundant basin. As a result the participants were more open to exploring potential futures where they and the industry they represent may not have access to water. Because this research did not result in a management recommendation stakeholders were able to loosen the grip on their 'stakes' and sincerely engage in hypothesis-driven, exploratory research.

Impacts of stakeholder engagement in transdisciplinary projects

WW2100 participants identified three kinds of success: research, process and personal. Previous literature emphasises the different ways to measure transdisciplinary project success. Scientists typically consider a project successful when it contributes long-lasting science in the form of a peer-reviewed article, while stakeholders typically consider a project successful when it results in tangible improvements to management (Johnson, 2011; Mackenzie et al., 2012; Mostert et al., 2007). Some researchers call for 'alternative measures of success' in transdisciplinary projects, arguing that the design experience may be more important than the results themselves (Lautenbach et al., 2009). A project might be called successful if it results in new relationships among participants, improved communication, accessible knowledge, useful tools, behaviour change or specific societal outcomes (e.g. Dilling and Lemos, 2011). Previous cases list stakeholder engagement successes but do not reflect on the perceptions and experiences of participants. Stakeholder engagement, facilitated by trusting relationships (Riley et al., 2011), may improve research quality (Bonney et al., 2009) and science-driven decision-making toward conservation, resilience and sustainability (Shirk et al., 2012). Without an impending decision it is difficult to measure the impact of a researcher-stakeholder engagement process on decision-making. Still, the process-oriented outcomes achieved through WW2100 may influence future water science and management in the Willamette Basin – indeed they already have, to some degree, as a number of participants have continued to work with researchers from the WW2100 team on new projects.

This study places the successes reported by WW2100 participants in the context of the NSF Broader Impacts review criteria as a framework for evaluating the impacts of stakeholder engagement. Alternative measures of success in the literature and WW2100's three types of success (process, research, personal) exemplify achievements of each of NSF's five broader impacts review criteria and elucidate an emerging sixth criterion: develop the research community (Table 3). The impact of stakeholder engagement in natural resource research can be discussed in terms of each review criterion: advancing scientific discovery and understanding, broadening participation of underrepresented groups, enhancing infrastructure for research and education, broadly disseminating results and benefitting society.

Stakeholder engagement advances scientific discovery by incorporating stakeholder knowledge and questions into scientific studies in a way that research teams would not have done alone. Stakeholders provided feedback on questions, model parameter assumptions, output metrics, modelling scenarios and interpretations in WW2100. Similarly, stakeholders helped to define process components, methods, design elements, output indicators and outcome plausibility in the development of a decision-support tool (Mahmoud et al., 2009). Participants also learned about scientific modelling, the research process, each other and each other's respective areas of expertise, thus increasing understanding. WW2100 advanced discovery and understanding by integrating new and traditional sources of knowledge and perspectives through stakeholder engagement. Finally, research products were made for stakeholder engagement events that would not have been made otherwise (Pearson et al., 1997), pushing the pace of project efforts.

WW2100 stakeholder engagement broadened the participation of underrepresented groups in research. Survey respondents who participated more in the WW2100 engagement process expressed a greater perception of feeling heard. Interviewees expressed gratitude for their level of involvement and the level of respect among participants. The process was also able to include actors not often associated with scientific research projects, such as tribal and agricultural representatives. Research may broaden the participation of underrepresented groups by inviting diverse, non-scientist participants to attend, as well as by ensuring that participants feel heard. This element is undocumented in previous literature and should be explored further.

Of all the NSF broader impact criteria, WW2100's stakeholder engagement process was most successful in enhancing research infrastructure. Interviewees felt that WW2100's most meaningful product was the resulting network of users, regulators and researchers and the water resources discussion that followed. A social network of stakeholders and researchers can be an essential asset in adapting to future changes by increasing adaptive capacity (Pahl-wostl, 2007), social capital (Leydesdorff and Ward, 2005) and learning (Manring, 2014). These process values are positively correlated with participation in WW2100's stakeholder engagement events.

Although forming partnerships falls within the NSF broader impacts criterion 'enhance research infrastructure', the prominence that developing a research network played in participant evaluations of WW2100's researcher-stakeholder engagement process leads this study to propose it as a sixth criterion to NSF's broader impacts criteria. Enhancing research infrastructure remains an important criterion, referring to building new facilities and instrumentation, just as WW2100 did with its new modelling framework, *Envision.* However, due to the strong emphasis on forming and strengthening relationships, a project may achieve broader impacts through developing the research community within and beyond academia.

Table 3. Proposed revisions to the NSF broader impact (BI) framework based on WW2100 findings.

BI review criteria	Revised BI review criteria	Specifications to criteria	Qualitative data	Quantitative data
Advance discovery and understanding	Advance discovery and understanding	Integrate new and traditional sources of knowledge and perspectives	*"Provided a feedback mechanism on what we're doing and whether it's reasonable or not"*	Process utility Model understanding
Broaden participation of underrepresented groups	Broaden participation of underrepresented groups	Diverse participants are present	*"I think the diversity is remarkable and respected"*	Attendance record
		Diverse participants feel heard	*"We're being listened to"*	Feeling heard
Enhance research infrastructure	Enhance research infrastructure	Build new facilities and instrumentation	*"We've built a model"*	Process utility
	Develop research community	Form and strengthen research partnerships and networks	*"The most meaningful product of projects like this is the connections between people"*	Process utility
Broad dissemination of results	Disseminate results broadly	Train stakeholder ambassadors of science	*"People take the output back to the groups they belong to"*	Model understanding
Benefit society	Benefit society	Science users believe results will benefit society	*"It just created a lot more buy-in from the users"*	Model utility

Stakeholder engagement processes also contribute to the broad dissemination of research results. By inviting stakeholders into the process WW2100 researchers built credibility for their tool, allowing it to work as intended (Lynam et al., 2010). This 'live peer review' (Halofsky et al., 2011) or 'extended peer review' process "improve[s] the legitimacy, credibility and relevance of science, especially in the context (…) where facts are uncertain, values in dispute, stakes high and decisions urgent" (Johnson, 2011: 265). Stakeholders are more likely to share tools with co-workers and apply them in their respective contexts when they believe they are credible. WW2100 stakeholders expressed that they would share what they had learned with others. Training stakeholder ambassadors of science will help a project to broadly disseminate its results.

The fifth broader impacts criterion – benefit society – is the broadest and perhaps most difficult to define and measure. In WW2100 participants believed the research results were useful but were also aware of their limitations. Still, participants valued the model as a useful way to understand the current processes (Santelmann et al., 2001) and to provide a basis for future water-resource discussions. As in all other categories participation in stakeholder engagement events positively correlated with a perception of the usefulness of the model and its results.

This work documents a correlative link between individuals' participation in researcher-stakeholder engagement events and achieving research broader impact goals. Interaction between researchers and science stakeholders can improve understanding of each other and of problems and solutions, as well as encourage trust, commitment and network formation (Dilling and Lemos, 2011; Mader et al., 2013; Mostert et al., 2007; Sol et al., 2013). Participation is a key contributor to successful stakeholder engagement projects. As explored above, there are at least five broad categories of broader impact success that depend on successful stakeholder engagement.

CONCLUSION

Researcher-stakeholder engagement processes are an effective method to achieve research broader impacts and to explore social-ecological system questions regarding water sustainability. WW2100 engaged stakeholders to answer the long-term research question of where and when water scarcity might occur over the next 100 years in a currently water-rich region as a result of climate change and population growth. A Broader Impacts Team facilitated the researcher-stakeholder engagement over five years and through various engagement techniques. Through this process researchers included stakeholder-provided data and integrated it across disciplines, producing a more complete and informative water model. This case study reports the perceptions and experiences of the researcher and stakeholder participants in this transdisciplinary researcher-stakeholder engagement process and documents challenges and successes as they relate to the NSF's broader impacts review criteria. Two lessons emerge for transdisciplinary research practitioners:

1. Facilitate conversations early in the process to arrive at a shared vision for the research project and process.
2. Dedicate adequate resources (time, money, personnel) to increase and foster meaningful stakeholder participation from project inception to completion in engagement events.

The value of researcher-stakeholder engagement is greater than the immediate impact of developing tools for management decisions. Active development of the research community is a valuable transdisciplinary research broader impact outcome – one that may influence the success of future science and management. Although the WW2100 project has concluded its researchers and stakeholders continue to collaborate in two notable ways. A subset of WW2100 researchers and stakeholders participate in the Urban Water Innovation Network (UWIN), where they build upon the WW2100 *Envision* water model to visualise tradeoffs between different urban water management strategies and responses to water system drivers. Additionally, informed by WW2100 results Oregon municipal water providers are requesting additional allocation of water stored in select dams. Thus, developing the research community, as the WW2100 project has, strengthens the network through which social learning and collaborative management may occur.

Stakeholder engagement changes the broader impacts preposition so that academic research is no longer 'to' or 'for' a faceless public but a mutually beneficial partnership 'with' natural resource stakeholders.

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