

Groundwater connected art: practicing arts-based research to enrich how hydrogeology engages people, place and other disciplines

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Abstract:

Groundwater depletion, contamination, and governance challenges persist despite decades of groundwater research. Scientific methods are crucial yet seem insufficient to inspire the deep emotional and cultural connections needed for real change – groundwater challenges and opportunities are not reaching enough hearts and minds. This article calls for a bold shift: integrating arts-based research into hydrogeology. By blending art forms like drama, visual art, storytelling and music with the scientific process, we can spark more powerful connections to this invisible yet vital resource. Examples of groundwater in diverse art practices already exist and could be expanded in manifold ways through expressions of groundwater tastes, smells, sounds, textures, movements, landscapes, cultures and connections in community and into the future. Art can bridge gaps across disciplines, reach broader communities, and offer fresh ways of thinking about groundwater. From ideation to data collection and communication, the creative process has the power to make hydrogeology more human, emotional, and impactful. This article invites groundwater and environmental scientists to embrace creativity and collaboration with artists and communities to change how we engage and value this invisible resource.

Keywords: arts-based research; hydrogeology; groundwater science; hydrology; environmental science; creativity; communication; interdisciplinary water research; socio-ecological systems

1. Motivation: Why hydrogeology needs art

Groundwater resources, sustainability and management face myriad challenges (Gleeson *et al* 2020, Bierkens and Wada 2019, Lall *et al* 2020, United Nations 2022). Groundwater problems are often approached with methods from a physical science, economics, policy studies and social science (Mace 2022). Importantly, interdisciplinary approaches are emerging such as socio-hydrogeology (Re 2021), ecohydrogeology (Cantonati *et al* 2020), groundwater connected systems (Huggins *et al* 2023) and critical social science (Zwarteveen *et al* 2021). Yet groundwater depletion and contamination persist or even accelerate (Jasechko *et al* 2024), and there is widespread lack of effective groundwater governance and policy implementation (Molle and Closas 2020), and internationally few civil society organizations focused on groundwater management or governance (FAO 2016). Groundwater governance is typically focused on command and control of individuals and pumps, instead of community initiatives to care for, share or recharge the aquifers they depend

on for livelihoods and incomes (Zwarteveen *et al* 2021, Dominguez Guzmán *et al* 2023). Science communication and media outreach are important and have raised the profile of groundwater (e.g. Gleeson *et al* 2019), but seem insufficient in changing the narrative and importance of groundwater. We are not reaching enough hearts and minds. Groundwater is literally invisible, yet we are a visible species, most often moved by beauty and narrative. Among groundwater and environmental scientists, groundwater is also usually considered and discussed in physical and rational ways, though we are also an emotional species, often motivated by feelings, relationships and values. To me, all these realities invite hydrogeologists to consider different forms of creativity, expression and collaboration, that may be uncomfortable for some.

The interface of science and art goes by different names (art-sci, sciart, ArtScience or STEAM - Science, Technology, Engineering, Arts, and Mathematics, etc.). For example 'ArtScience' involves understanding the human experience of nature through the synthesis of artistic (subjective, sensory, emotional, and personal) and scientific (objective, analytical, rational, public) modes of exploration and expression, enabling us to achieve a more complete and universal understanding (Root-Bernstein, *et al* 2010). An astounding variety of artistic methods are possible including drawing, illustration, storytelling, performance, theatre, dance, writing, music, audio, photography, sculpture, land art, painting, video, weaving and textiles. Savenije (2009) argues that art is essential to developing new hydrologic insights and research approaches as well as more holistic hydrologic models that better represent the inherent hydrologic uncertainty (Beven 2017). Creative thinking draws upon two distinct kinds of mental processes: fast thinking which produces intuition, and slow thinking that produces reasoning. Scientists often consider science itself creative but scientific practices almost entirely focus on slow thinking, while art promotes fast thinking that can catalyze scientific progress and breakthroughs (Scheffer *et al* 2015). Scientists sometimes use arts in science communication and dissemination, which is useful and necessary, but arts-based research methods suggest that art can be usefully applied across the whole research process in hydrogeology and more broadly the physical and environmental sciences.

Arts-based research is the systematic use of the artistic process as a primary way of understanding and examining experience (McNiff 2008) and is known by numerous other terms summarized by (Leavy 2018). Art can be used across the research process to collect, interpret, analyze, or present data, and it often aims to capture and express complexities and ambiguities (White and Cooper 2022, Beven 2017). Both arts-based research and science involve the use of clear methods and systematic experimentation with the goal of gaining knowledge about the world (McNiff 2008), although art can access different and multiple ways of knowing compared to science. Arts practices can be useful for a myriad of reasons including connecting and communicating emotionally across differences, fostering imagination, exploring different possibilities and futures, accessing knowledge that is challenging to access with science, and facilitating engagement with the body and complex emotions (McNiff 2008, Greenwood 2019, Leavy 2018). Two broad approaches are *arts-related research* which involves reflection on preexisting artworks, and *arts-informed research* which involves art in one or more phases of research from ideation, data collection, data analysis and communication. Arts-based research is rooted in participatory and community-based social science with participants, researchers & artists working together (McNiff

2008), deepening and broadening peoples connection to research. Groundwater connected art can be considered any artistic expression of groundwater; although there are numerous examples of groundwater connected art, to my best knowledge groundwater connected art has never been systematically described or proposed as a process and outcome of integrating art-based research and hydrogeology.

My objective is to invite fellow hydrogeologists to engage in arts-based research, fostering deeper, more diverse, and more impactful connections to groundwater. By incorporating artistic practices, hydrogeology can engage broader audiences, enrich the research process and researchers themselves, and hopefully inspire a shift in how society values and protects groundwater. This article contributes directly to several priorities in this Special Issue on ‘Progress in Socio-Hydrogeology’. Groundwater connected art enables conceptualizing groundwater through a socio-cultural lens and better representing cultural values, knowledge and understandings of groundwater. Further, arts-based research can enable a more participatory approaches to groundwater science, and explicitly elevates the importance of inclusion and justice. Hydrogeology and groundwater are the focus of this article, but some of these approaches may be useful or interesting in other physical science or environmental fields.

This article unfolds through a series of invitations, to you dear reader: to elevate groundwater’s presence in diverse preexisting artworks (Section 2), to envision expansive and integrated representations of groundwater (Section 3), to engage with art and artists within communities (Section 4), and to explore how the hydrogeology community might embrace art (Section 5). Since “art embraces ordinary things with an eye for their unusual and extraordinary qualities” (McNiff 2008) I even invite you to approach this article or a research project as an artist: *try to have an eye for anything unusual or extraordinary in this ordinary article or in one of your ordinary research projects*. We’ll check in about if you found anything unusual, extraordinary, beautiful, impactful or ugly at the end of the article.

I introduce my background to give context to these invitations. I am a hydrogeologist with limited formal arts training; I hope that writing from this perspective and background makes art and arts-based research more accessible and visible for others with a similar background. I previously focused on how to ‘visualize’ groundwater through graphs, maps and models which can be viewed as art, but these traditional scientific approaches haven’t nurtured my creativity enough. I have started trying arts practices (described mostly in Box 1 as just one humble example of how a scientist can start to bring art into their work) and have found this deeply inspiring and energizing work that challenges me to question and deconstruct my deep biases and assumptions of what is valuable, good and useful (further described in Box 2). It is important to acknowledge my many unearned privileges as an able-bodied, cis-male, hetero white settler including access to nature, art workshops and supplies; barriers including a lack of formal art training, confidence and identity. These artistic approaches are new and inspiring to me, but for others have been the focus of their career and work for years. So, I bring an open beginner’s mind to this and try to incorporate previous learnings and projects, but will inevitably be incomplete and biased.

For such interdisciplinary work, it is important to clarify terminology. Scientists sometimes use the word 'art' in a general sense (such Savenije, 2009 and many "state of the art" reviews), but this article follows Beven (2017) and other scientists directly practicing artistic methods and/or collaborating with artists. It is also important to note that the word 'art' can infer polished products but here any and all creative processes and products are emphasized; art can be rough, done, undone or many other adjectives. I have found the word 'beautiful' to be a useful term in my art-sci practice since it opens my mind to a different and more aesthetic way of considering groundwater. Yet, beauty is a subjective, critiqued concept and art can also be ugly, challenging and provocative. So, if useful, I encourage you to substitute 'beautiful' with other phrases such as 'emotionally impactful', 'affective', 'impactful', 'connecting' etc.

2. Groundwater in diverse art practices – groundwater can be beautiful!

The first invitation is considering groundwater's presence in diverse preexisting artworks which is the approach of '*arts-related research*' in arts-based research. Can wet dirt and rocks really be beautiful? Macfarlane (2019) argues that humans are both intrigued and disinclined to imagine or represent the subsurface, that "for many reasons we turn away from what lies underneath". And Beven (2017) suggests that representing the dynamics of flowing water in two-dimensional images may be one of the greatest artistic challenges, which is further compounded for groundwater which flows invisibly underground. Figure 1 brings to the surface a few varied examples of groundwater-focused art from diverse art practices. Only visual examples are possible in Figure 1 given the format of this article. To explore other artistic forms while reading you could listen to Kevin Befus' spotify list 'the best/only groundwater songs' (see [blog post](#)), watch Inception Horizon (Figure 1e) or read 'Why We Cry' and the inter-connected dissertation on the need and practice of storying groundwater (Wardle 2018).

I do not analyse or critique specific groundwater-focused art pieces in Figure 1 given my limited arts training, but to me they all reflect ways that groundwater can be beautiful. These examples are from internet and social media searches of 'art' and 'groundwater' or 'aquifer', as well as my research network. They are meant to be illustrative and diverse in their art form and geography rather than comprehensive. Compared to other aspects of the physical environment (rivers, mountains, ocean etc.) there overall seems to be much less art focused on groundwater. The publicly and digitally accessible examples are diverse in their art form and geography but are primarily from the global north. Art can be political, and it is interesting to consider if or how some of the art in Figure 1 is political, purposefully or not. For example, the 'groundwater imaginaries' drawings co-created by the Transformations to Groundwater Sustainability network (Zwarteveen *et al* 2021) capture the complexities of community groundwater practices in the different places (Figure 1g). I am excited to see more examples from the global south/world's majority as well as from more arts forms such as storytelling, dance, photography, land art, video, weaving/textiles, or digital arts. I am sure that much more groundwater-related art that has been created in various arts, science, and place-based communities around the world, some of which may be less accessible or public.

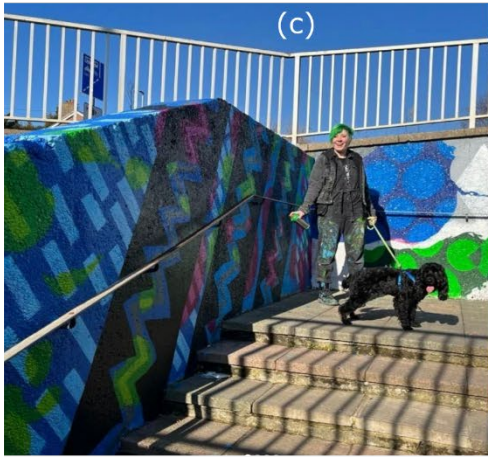
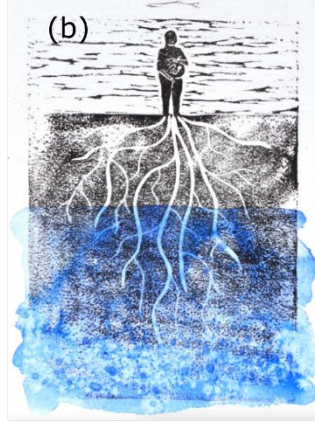


Figure 1. Groundwater-related art in different media including drama, illustration, graffiti, sculpture and music. (a) Dushman play about groundwater versus bottled water presented by Punjab Sangeet Natak Akademi ([source](#)). (b) ‘Connections’ created by Louise Arnal in conversation with Grant Ferguson and Jennifer C. McIntosh ([source](#)). (c) The Coldean Lane Underpass Mural is a beautiful tribute to the aquifer and its significance in sustaining our communities for generations to come (still image from [video](#); contacted [the Aquifer Partnership](#)). (d) ‘High Plains Transitional Spaces’ by Steve Rossi. Structural Impediments solo exhibition installation view; Freedman Gallery, Albright College, Reading, Pennsylvania 2023 ([source](#)). (e) Inception Horizon is a choral song inspired by adventures at the Devil’s Punchbowl in Ireland and deep inside Slieve Elva and guided by the insightful scientific explanations of Dr. Laurence Gill and composition by Norah Constance Walsh (still image from [video](#)). (f) The Holy Well by Frederick Goodhall [link](#) or etching [link](#) (g) The Participatory Groundwater Management Initiative in Randullabad, India (Co-produced by Uma Aslekar, Dhaval Joshi, Rucha Deshmukh and Cristian Olmos Herrera) from (Zwarteveen *et al* 2021). I have tried to reach out to the appropriate creator of each of these images, and most have informally approved inclusion in this article, but not been able to get a hold of every creator. Images are included in this preprint for the sake of the review process but will only be included in the final article if full permission is granted.

Indigenous expressions of groundwater art are also important to foreground and elevate. Cultural relationships and dependence of Aboriginal people on groundwater have been described by Kamilaroi hydrogeologist, Bradley Moggridge, including a painting titled Three Waters that represents three significant groundwater sources in the ancestral country (Moggridge 2020). Moggridge (2020) importantly states that "Aboriginal art is not a static relic of a bygone era but a vital and pertinent expression of current human concerns." Groundwater has been used as a metaphor for art therapy training at the Kutenai Art Therapy Institute (KATI) since groundwater brings together the earth/ground and water/life/emotion; this initiative advocates for Indigenous-centered art therapy education while committing to ongoing processes of decolonization and reconciliation (Carpendale 2023). Arts-based research has also been elevated as a useful approach for Indigenous evaluation (Rowe 2022) or see season 2 of the [Indigenous Insights podcast](#). It is valuable to foreground and elevate examples of Indigenous and traditional examples of groundwater connected art, but I don’t include Indigenous examples in Figure 1 since from my settler social location this could be inappropriate, or potentially appropriative. Instead following the anti-racist approach of foregrounding into my own ancestry, I include a historic painting of a holy well from Ireland (Figure 1f), Celtic and Christian sacred sites that have also been studied scientifically (Misstear 2023). I invite important future work of describing, foregrounding, elevating, analyzing and critiquing diverse examples of groundwater connected art both from the past and today.

3. Groundwater landscapes and cultures in community and into the future: groundwater connections are beautiful!

The second invitation is envisioning expansive and integrated representations of groundwater. Since groundwater is literally invisible, instead of only thinking of groundwater as a physical or geological entity, a more holistic approach to groundwater and art considers all the connections and functions of groundwater. The groundwater-connected systems framing (Huggins et al. 2023) advances groundwater as a social ecological system with underacknowledged, inherent and life-sustaining connections to ecosystems, food systems, water management systems and Earth systems. Like the groundwater connected systems framing, groundwater connected art aims to represent groundwater much more holistically. The foundations and approaches of these two ideas are complementary but quite different (social-ecological systems vs. arts-based research). Some of these connections include growing food, supporting economies and sustaining culturally significant rivers and sacred places like springs. Macfarlane (2019) argues even more broadly that across epochs and cultures the subsurface serves three main functions: to shelter what is precious (memories, precious matter, messages, fragile lives), to yield what is valuable (information, wealth, metaphors, minerals, visions) and to dispose what is harmful (waste, trauma, poison, secrets). I foresee limitless possibilities of combining the holistic approach of groundwater connected systems and functions with the diverse forms of arts-based research. Figure 2 illustrates some examples of the possible topics or subjects of this approach (the ‘what’) while Section 3 describes how we could more fully use arts-based research (the ‘how’). It is important to underscore that these eclectic examples are from my limited background and only a small representation of the limitless possible topics or subjects. Some questions for inspiration are: What are everyday connections to groundwater? What are beautiful connections? What are examples of beautiful groundwater in built and natural landscapes? What beautiful built or natural landscapes could we re-interpret as groundwater landscapes? What beautiful groundwater-related futures could we imagine? Let’s explore a few example imaginations below (and while doing so, maybe reflect on how imagination could be strengthened in hydrogeology).

The groundwater-connected systems framing was first visualized as a generalized regional conceptual model depicting important economic, social, political aspects along with the physical and geological setting (Figure 2a) – this visualization is useful for physical scientists familiar with similar cross-sections and conceptual models since it is in a similar visual language while also showing what is new and different in this framing. Such conceptual models could be considered a form of art, expressing a scientist’s understanding of the system. But any idea can be expressed in a myriad of ways that may be more impactful for people of other backgrounds. Figure 2 includes two more examples of expressing ‘groundwater connected systems’ using generative artificial intelligence (Figure 2b) or abstract painting (Figure 2c) but imagine all the other possibilities with storytelling, dance, land art or weaving. We can also imagine varied art forms representing places and times where groundwater is connected to people. Obvious examples of this include sacred sites such as Shinto shrines in Japan where groundwater is considered sacred (Figure 2d), or hot spring bathing cultures such as in Iceland or Japan (Figure 2e). In places where people gather

around wells to gather water, wells can be important focal points of social interaction and/or spiritual practices. Another type of subsurface connection that is gaining awareness (and could be fruitful inspiration for groundwater connected art!) are mycorrhizal relationship that transform forests from isolated individuals into interdependent communities (Simard 2021). A more subtle example is elevating and expressing groundwater connections at a stakeholder or project meeting (Figure 2f). Imagine hosting the meeting beside a groundwater-dependent river or spring (that may be affected by groundwater pumping), serving food grown by groundwater and maybe even making some art expressing how the food, farming, people and groundwater are all relationally connected in specific and important ways in this place. A natural setting where groundwater comes through in various different ways could lead to greater equity - there is no single expert on the topic because the setting highlights the natural connections and complementarity between people's expertise.

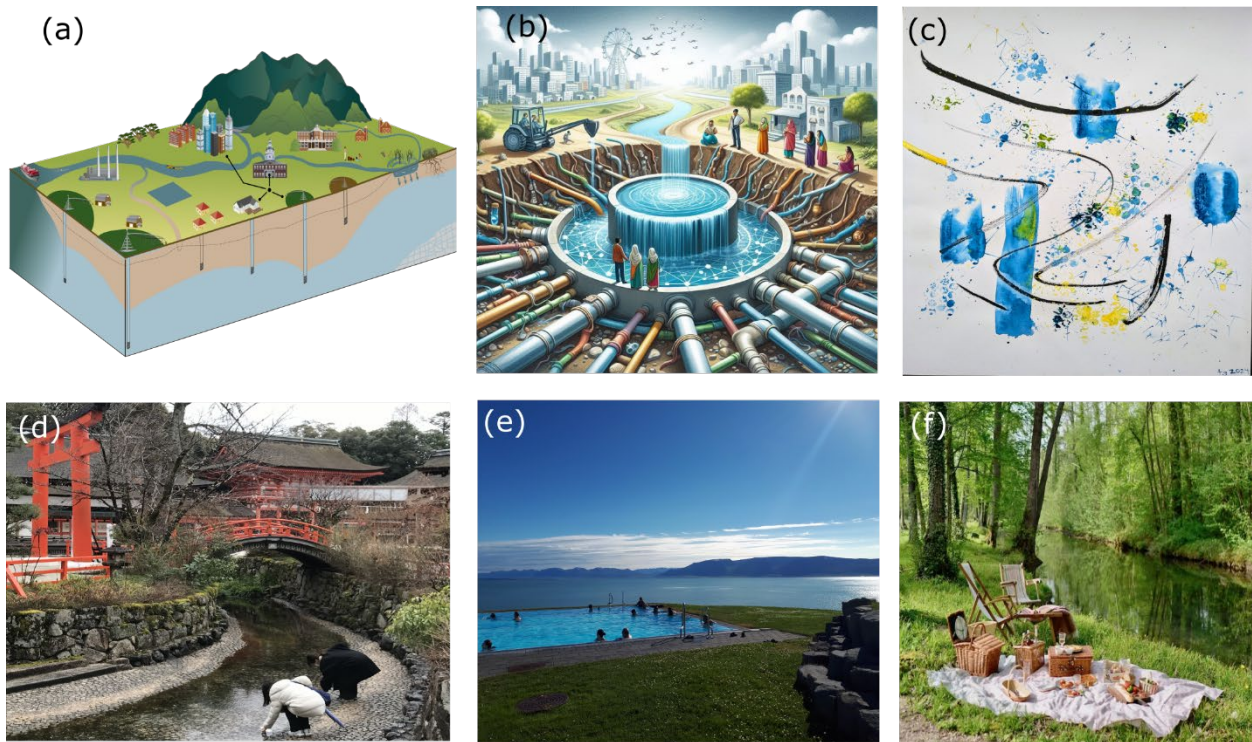


Figure 2. Different artistic expressions or inspirations of groundwater. Three different ways of expressing 'groundwater connected systems' with (a) generalized regional conceptual model (Huggins et al. 2023), (b) generative AI (DALL-E 3 by OpenAI) created image with prompts from author, and (c) abstract illustration by the author. Imagine all the different possible ways of expressing 'groundwater connected systems' using different artistic methods by different people in different places. Or even more broadly, imagine groundwater art that expresses groundwater's (d) spiritual value such as at temples and shrines in Japan, (e) community and cultural value such as bathing cultures in Iceland or (f) hosting a groundwater stakeholder meeting beside this groundwater-dependent stream, serving groundwater derived food while making groundwater related art.

4. Bringing arts practices into hydrogeology: beautifully engaging with beautiful groundwater

The third invitation is engaging with art and artists within communities which is the ‘arts-informed’ approach in arts-based research. This involves the art process in one or more phases of research from ideation, data collection, data analysis and communication. Some form of interdisciplinary collaboration, interaction or work likely nurtured or supported the examples in Figure 1. I foresee that art can be an important connector between place-based communities and the hydrogeology community (Figure 3). The overlaps in Figure 3 of community-based arts, community-based research and art-sci are all well described elsewhere, so here I focus on describing community-based art-sci starting with an example of a recent project.

Community-based art-sci involves place-based communities using both artistic and scientific processes to express themselves, further their priorities or understand their experience of nature. An example of community-based art-sci is ‘Project 84,000’ where community members in the Cowichan Valley, British Columbia have created 84,000 fish rubbings to honour the estimated 84,000 trout that died in the Cowichan River in July 2023 due to environmental stress (Figure 3c). Using collagraph prints of cut-out fish shapes, over a thousand people, from school-aged children to Elders, have rubbed these shapes onto long rolls of brown craft paper with wax crayons. The project has scientific, artistic and community-focused goals of honouring water, fish and their watershed habitats in five ways: 1) visualize the number 84,000 and begin to comprehend the immensity of the loss of life; 2) grow skills to stay present in ourselves when grief arises while growing bonds of connection and healing in community; 3) express and honour our love of the natural world and our place in it; 4) learn from facts and factors that contribute to this kind of ecological disaster; and 5) encourage dialogue and other forms of stewardship actions we can take individually and collectively. This project is analogue and importantly based on ecological grief of the past.

Community-based art-sci could also use digital tools and/or focus on the present or future, such as seeds of the good Anthropocene (Bennett *et al* 2016). Examples of digital tools include generative AI (like Figure 2b) to develop new ways of an imagining or expressing groundwater connections, or virtual reality simulations to represent how a physical groundwater model would change for different scenarios, futures and connections. Futures and scenarios (Wiebe *et al* 2018) can be a generative focus of community-based art-sci using either digital or analogue approaches – for inspiration explore [biosphere futures](#), a global collection of place-based social-ecological scenario case studies. A guiding question could be: how can we use art to heal the past, promote sustainable current practices and build beautiful, positive groundwater futures?

Arts-based research can also be useful in making connections in large interdisciplinary groundwater-related projects and initiatives. For example, the climate adaptation and resilience in tropical drylands (CLARITY) project uses art-based research when convening transformational labs (collaborative spaces where people co-develop sustainable, equitable pathways to build climate resilience) in the Sahel (Maradi region in Niger), and the drylands of central Tanzania (Dodoma).

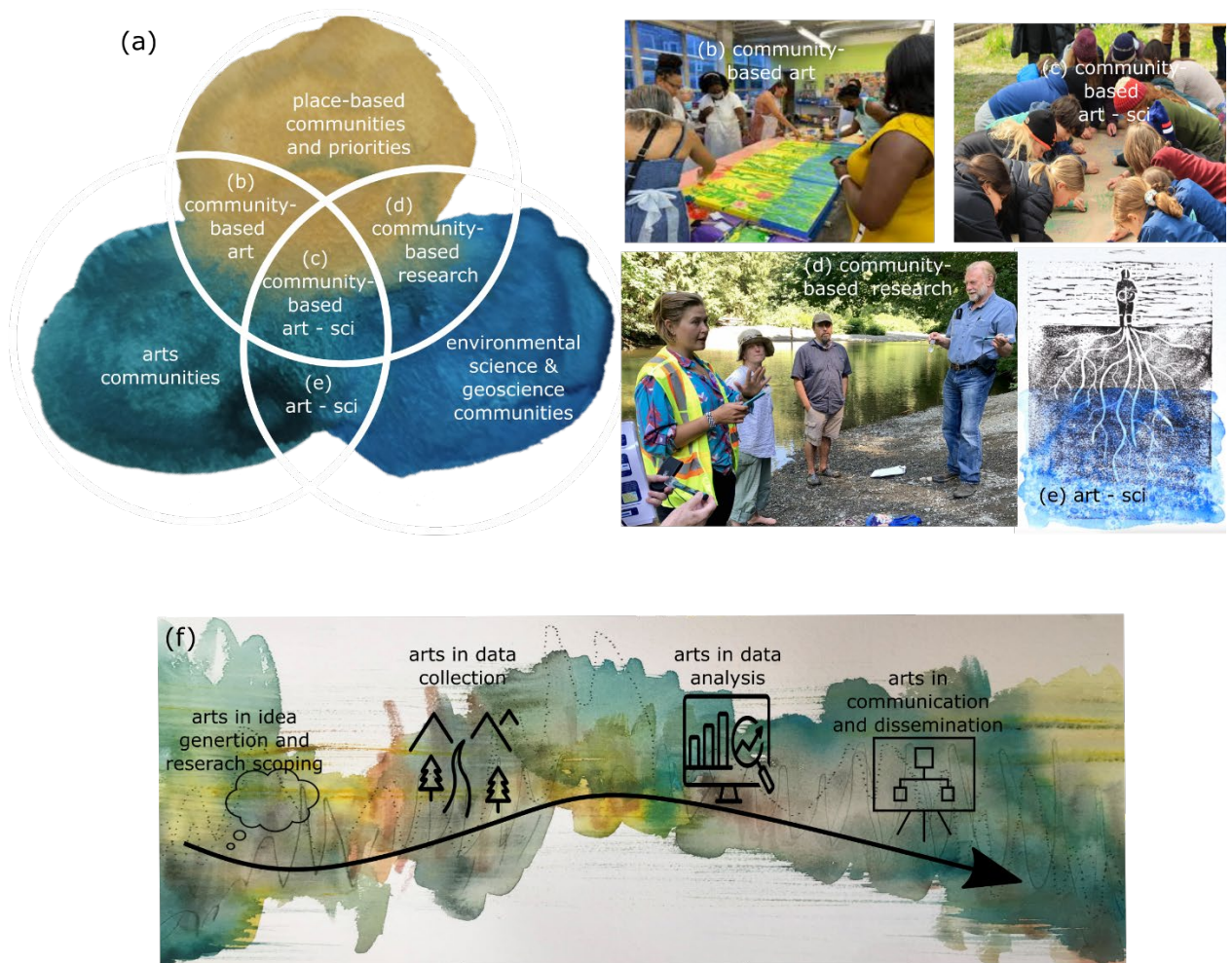


Figure 3. a) Painted Venn diagram showing the overlap between place-based communities and priorities, art communities and environmental science and geoscience communities. At these overlaps and shown in example photographs are (b) community-based arts, (c) community-based art-sci, (d) community-based research and (e) art-sci. (f) Arts-based research can be used at any or all of the stages of research from initiation to dissemination. Paintings by the author.

Another analogue and community-based example is drawing experiences, ideas and findings as ‘groundwater imaginaries’ (Figure 1g) that have been useful as a tool for interpretation and critical reflection, as well a joyful way to start practicing care and solidarity (Zwarteveen *et al* 2021). A guiding question could be: how can we use art to bridge differences across disciplines as well as place-based communities?

An important outstanding question is: what is the role of physically trained scientists in creating or supporting the creation of groundwater connected art? I have asked this question of myself and numerous colleagues with similar backgrounds and found divergent responses. Some people are enthusiastic, pulling me aside to talk about some art that they did, were part of, or excited to try. But others are reticent, doubtful or critical with a few common responses such as ‘I’m not an artist’ or ‘this is not my role or training’ or ‘it would be inappropriate since I don’t have the skills or training’. I give voice to some of these reluctances in Figure 4, and further explore the underlying reasons and possible antidotes to these responses in Box 2. Both types of responses are legitimate and reasonable, and every scientist answers this question differently, and their answers may change over time as they move through the internal and external changes that are necessary for scientists to deepen their engagement with art. Anyone can create art to express themselves, so I strongly argue that arts practices can be done by anyone. Professional artists and others with significant arts training have skills and capacities that is important to respect (like physical scientists have skills and capacities for physical science), rather than unquestioningly ‘doing art’ in a professional setting. Thus, I believe that in a professional setting it is important to act from and clearly state your social location, training and purpose and when possible, also engage with arts and place-based communities (Figure 3).

5. Concluding with an invitation to try art

The final invitation is exploring how the hydrogeology community might embrace art. I invite you, dear reader, to imagine yourself in Figure 4 or a similar environment. What do you imagine sensing? How does it feel? Is it inspiring or interesting? The beauty of arts-based research lies not only in what it reveals but also in how it engages our senses, emotions, and intellect - it’s a vibrant space where creativity and scholarship dance together (Greenwood 2019). So what would it be like for more hydrogeologists to join this vibrant space and dance? Hydrogeologists engaging arts-based research will likely have to work through their barriers as scientists (Box 2) as well deep the cultural disinclination to represent the subsurface (Macfarlane 2019). Dominguez Guzmán *et al* (2023) argue for the importance of practices in the transformations to groundwater sustainability including *situating* (particularising existing groundwater knowledge in the specific contexts and networks in which it arose or is arising), *caring* (emotionally and practically engaging to restore, sustain, or protect groundwater) and *tinkering* (engaging groundwater in patched together and always in-the-making ways). I am interested how arts-based research offers opportunities for hydrogeologists to deepen how they situate, care and tinker with groundwater.

Now that you have seen a few examples, expressions, and inspirations of groundwater in art, it is important to reiterate that arts practices can be useful for a myriad of reasons including connecting and communicating emotionally across differences, fostering imagination, exploring different possibilities and futures, accessing knowledge that is challenging to access with science, and facilitating engagement with the body and complex emotions. Personally, I have found that art is an important growth and therapy for my linear mind, an exciting and different way of expressing myself, and something I want to lean into in collaboration with artists, communities and other scientists (further described in Box 1).



Figure 4. Two possible imaginations of groundwater art-sci collectives with scientists and artists engaged in a variety of analogue and digital artistic practices, both individually and collaborating in small groups either (a) inside or (b) outside. Some of the people may have reluctances (shown in the cloud thought bubbles) that could be mitigated with various responses (shown in the square thought bubbles). These reluctances help maintain and protect our self/identity (I'm not an artist), our discipline (scientists shouldn't do art), our philosophy (science doesn't need art) and worklife (I'm too busy for art) and are discussed more in Box 2. Generative AI (DALL-E 3 by OpenAI) image with prompts and thought bubbles by author. The misspelt 'gundwater' is clearly visible but is kept in the image as a simple reminder of the limitations of AI generated images.

I invite you to try incorporating art into your science. It could be exhilarating: real people, doing art and science together in place, on real issues. We can even imagine establishing a community of practice that has global impact. Figure 4 visualizes a groundwater art-sci collective with scientists and artists engaged in a variety of analogue and digital artistic practices, both individually and collaborating in small groups. Or we could grow a global network with nodes of scientists and artists working in place-based communities, trying whatever works for them in their projects in their places, and then sharing what worked and what didn't with the community of practice. These initiatives could lead to more public-facing groundwater-connected art, potentially as part of the [Science Gallery network](#). For me, it would also be important that such initiatives be values-based with clear intentions (since art can and has been used for oppression, propaganda etc.) and include anti-racist and feminist practices (Zwarteveen *et al* 2021, Dominguez Guzmán *et al* 2023). It is inspiring to imagine a 'theory of change' (Anderson 2006) for this work and what type of implications or changes this could make to groundwater policy, management and governance. But it seems premature to ruminate or pontificate on this since this approach of integrating arts-based research and hydrogeology is so nascent.

These exciting possibilities raise many questions for future research and practice:

- How can arts practices help bring more insights, connect across disciplinary differences?
- How can art help connect to place-based communities in new ways that reach more people and relate more emotionally or creatively?
- How can we grow a values-based, groundwater art-sci collective or community of practice that can support and elevate positive groundwater futures?
- How can arts practices enable decolonizing hydrogeology and elevate anti-racist and feminist approaches?
- How can we complement hydrogeology with art-based research in our data collection and analysis?
- What is the possible and ethical role of genAI for image, text and video of these hard to imagine realities, connections and functions?
- How can hydrogeology learn from other sciences have embraced art? How can the ideas and practices in this article be useful for other physical and environmental science fields?

To end, I return to my earlier prompt to have an eye for anything unusual or extraordinary in this ordinary article or in one of your ordinary research projects. Did anything catch your eye? If not, maybe go outside to your favourite local spring or groundwater-dependent stream, and try again – it is a lot of work and practice to change how we see the world! And maybe while you are there, try to draw, sing, dance!

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Box 1 - My art journey, so far

I humbly share a personal narrative of my art journey for a few reasons: stories can be powerful, as an example that any scientist can lean into their creative side, and to bring more personal vulnerability by sharing more of my challenges and excitements. I share it here to not overly center myself in the main article.

I loved drawing as a kid and creative writing as a young adult, and I remember watching my Mom practice various types of art (quilting, painting, piano, singing, calligraphy etc.). But my attention to creativity dwindled during my education and early years as a professor to the occasional haiku or nicely arranged dinner plate. I am a visual person and for my whole professional life, I have been unsatisfied by how we visualize the invisible water beneath our feet ([link](#) 2015 blog post). Cross-sections and conceptual models feel useful but uninspiring and incomplete, and for years I have been asking colleagues ‘how can we better visualize the invisible?’. But the answers also felt flat and unsatisfying.

During the pandemic, I was inspired to renew my creative side, and since have taken various drawing and painting classes, and spent time at home and in nature making art. But I could not figure out if or how creativity and art could interact with my science, research and teaching. This started changing while I was recently on sabbatical in Japan and Costa Rica. Seeing the fusion of

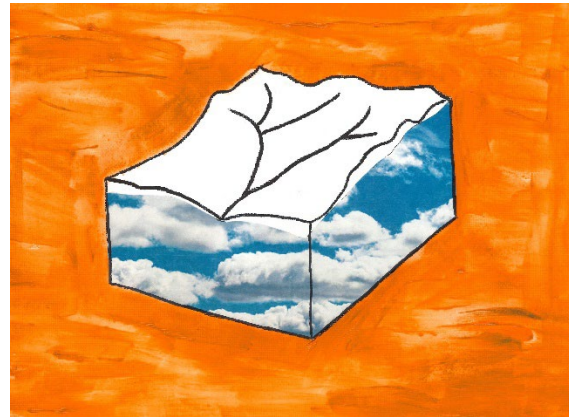
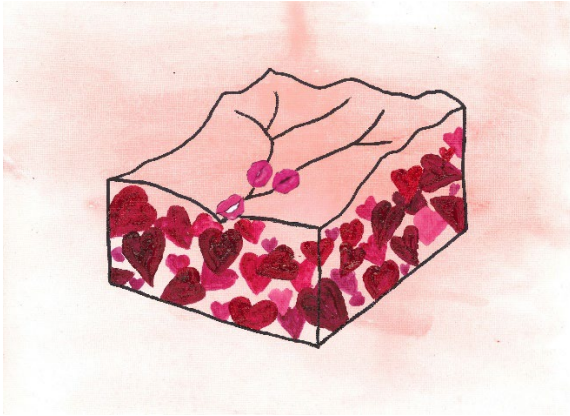
science and art by the SceNE Project at the Research Institute for Humanity and Nature in Japan ([link](#)) helped me see a way to bring more art into science projects.

Then while I was in Costa Rica on sabbatical, I was drawing natural landscapes and also trying to express the ‘groundwater-connected systems’ framing in a different way (Figure 2). The two images below are poignant to me since they highlight both the opportunities and challenges I felt. The first drawing (called ‘parent and child’) tries to capture the beauty of tree relations and reminds me of walking there with my own son and feeling very connected and grateful for my relationships to him and the more than human world. The second drawing (inspired by the first), has a groundwater flow system below the surface, and then an artesian-type fountain of water with icons of the different functions of groundwater spouts of water (like the limbs of a tree). Below the ground is generally physically plausible, but such a artesian type fountain is highly unlikely. I kept drawing cross-sections – I was so well trained to visualize groundwater this way, that my overly linear brain could do anything different!



More recently, I was inspired to try to express groundwater’s characteristics of invisible and distributed (Villholth and Conti 2017) in new ways. This started as metaphors that ‘groundwater is invisible, like love’ and ‘groundwater is everywhere, like air’ which I then tried to represent visually below. While I was working on these images, I appreciated how I could integrate my deep understanding of the relationship between topography, water tables and groundwater-surface water interactions (Gleeson *et al* 2011) into what I was trying to express. I was starting to have delusions of grandeur, imaging showing these at AGU in a sci-art exhibit, when my son asked ‘why do you keep painting that tree?’ referring to the river network I had drawn on the top of the 3D watersheds. I started showing these to colleagues and some immediately could see the watershed and started guessing a what I was trying to express. Other colleagues mentioned that they thought the river network looks like reindeer antlers with a red chocolate bar below. All of this was humbling and highlighted that my visual expression is maybe not that effective. But I will keep trying and would love to see what others can do with such metaphors in various artistic methods! Throughout all of this, I was questioning how obvious and explanatory I should be (even

thinking of putting the title of the piece directly on the painting so less people would be confused). This was me thinking that I was making another scientific figure that should be quickly and clearly legible, but art is not always quickly understood, and often has multiple meanings and interpretations.



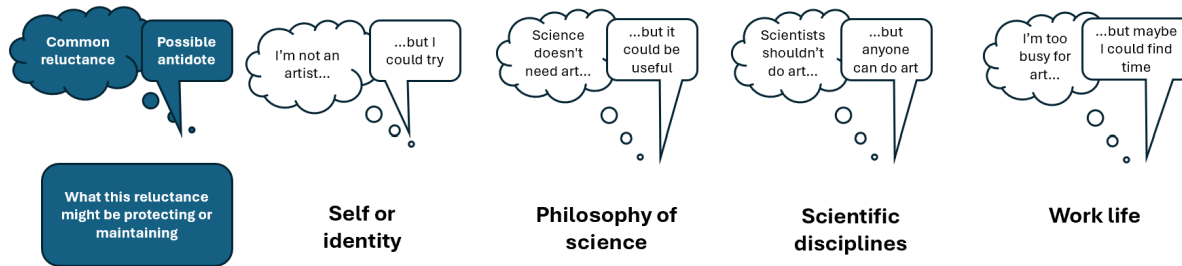
Box 2 - Exploring reticent, doubtful or critical reactions

There are numerous legitimate and reasonable reasons for scientists to be reticent, doubtful or critical of this approach. Wimpenny and Savin-Baden (2014) explore the challenges faced by researchers in integrating arts-based methodologies, including the epistemological differences between scientific and artistic approaches, concerns about rigor, and the difficulty in evaluating artistic outputs in a traditional scientific framework. More broadly, Robinson (2001) describe the challenges to practicing and promoting creativity in our modern, corporatized and science-focused society. But here I focus on my reflections after conversations with groundwater research colleagues since these may be more relevant to the readers of this article, especially anyone who is interested in questioning their beliefs.

As I continued to consider the possibility of engaging more with art as a scientist, I started noticing multiple barriers within thinking. Two of these that I mention in the main article were 'this is not my role or training' or 'it would be inappropriate since I don't have the skills or training', and I third one subtle one, was 'I can do art on my own, but not in a professional setting'. I have found that I can mitigate and sometimes move through these barriers through both internal reflection and external dialogue. For example, as I discussed the last barrier mentioned above with others in a workshop setting, I was reminded that 'professional' is often coded language for gatekeeping, and especially with my social location, it is best to careful with this. This led to internal reflections on how I need to redefine 'professional' in my life and loosen the stranglehold

it had on my sense of self and value in the world. These external and internal shifts helped me see more clearly what I could bring and offer to the world as a physically-trained scientist working in a professional setting in a colonial institution (a university) who is interested in engage more deeply with art and artists.

As I have discussed the possibility of practicing arts-based research as a groundwater scientist and with other groundwater scientists, I have found some consistent reactions, which I explore a little more next. My experience is that reticent, doubtful or critical responses come in different flavours and might be protecting or maintaining different things (see image below). I have found each of these within myself at different times, as I unpack my own beliefs that limit my ability to lean into art. I expect that most scientists have some of these self-limiting beliefs. These are just some of the reluctances I have noticed within myself and close colleagues, but I expect there are more, and the antidotes are just one possible way of countering this barrier – each of us have to find our own way through... As I ended the article - it a lot of work to change how we see the world!



Supplementary information

Prompts for the AI-generated art

I used Generative AI to generate images for Figures 2 and 4. Emerging best practices for using GenAI including providing a clear description of how and when you used GenAI tools, including the following details:

1. Context and Purpose:
 - Explain why you decided to use GenAI for a specific task.
 - Describe the purpose of using GenAI (e.g., brainstorming, generating ideas, improving writing, etc.).
2. Specific Tool and Date/Time:
 - Mention the GenAI tool you used (e.g., ChatGPT, Gemini, Copilot).
 - Provide the date and time when you interacted with the tool.
3. Example Prompts:
 - Include the prompts or questions you used to engage with the GenAI tool.
 - These prompts serve as starting points for the AI's responses.

For Figures 2 and 4:

1. I used generative AI tools to brainstorm how it would visually express different ideas that I had in my mind, but was struggling with how to draw. As I started generating images, I felt like these could be useful for readers of this manuscript so I have included them as figures.
2. The generative AI tool I used was DALL-E 3 by OpenAI which is now integrated into ChatGPT. The Figure 2 image was generated in August 22, 2024 and the Figure 4 images were generated on September 22, 2024.
3. Prompt for Figure 2b: Please create an image of 'groundwater connected systems'.
Prompt for Figure 4b: Please create an image of a summer 'art' camp for groundwater scientists to learn about and practice arts-based research.
Prompt for Figure 4a: great - What about an inspiring version of this but as an online hybrid meeting?