Water and Us: tales and hands-on laboratories to educate on sustainable and nonconflictual water resources management

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Abstract.

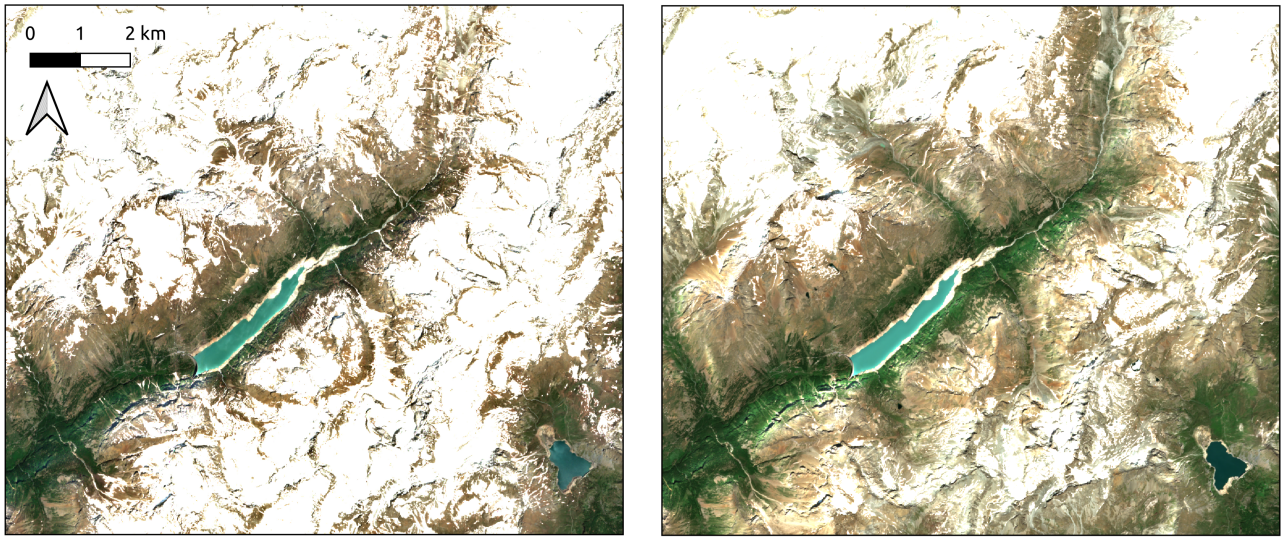
Climate change and water security are among the grand challenges of the 21st century, but literacy on these matters among high-school students is often unsystematic and/or ~~far~~ detached from the real world. To contribute to advancing education in a warming climate~~and prepare next generations to play their role in future societies,~~ , we designed "Water and Us", a three-module initiative focusing on the natural and anthropogenic water cycle, climate change, and emerging water conflicts. The method of Water and Us ~~resolves~~ revolves around storytelling to aid understanding and generate new knowledge, learning by doing, a flipped classroom environment, and a constant link to examples from the real world – such as ~~the archetypal events of the California snow drought or the~~ ongoing droughts across the world or seeds of conflicts around transnational river basins. Water and Us was established in 2021, and since then has involved 200+ students in a proof of concept to test the didactic approach in small-scale experiments. Results from 40+ hours of events ~~confirm~~ preliminarily confirmed that students are generally aware of climate change (90%), but have sparse knowledge of the concrete actions that are in place to mitigate or adapt (up to 20%). Understanding of the water cycle by students is often anchored to a naturalistic, but ~~fictitious~~ idealized view where human interference is minimal. ~~Our~~ In this framework, our approach conveys key elements of the contemporary, natural/anthropogenic water cycle, how this cycle is challenged by warmer temperatures and declining snowpacks, and how ~~education can contribute to avoiding maladaptation and conflicts . While this initiative is being channelled in awareness projects at various levels, the~~ climate change may ultimately lead to water conflicts if not properly managed. The Water and Us team remains interested in networking with colleagues and potential recipients to scale up and further develop this work.

~~Prologue: a tale of water and snow~~

~~Winter 2021-22 hit the ground running in Italy, with the first snowflakes falling across the Alps in early November. Snow returned between November and early December, when a second large storm hit most Italian mountain ranges. Early snowfalls peaked on December 8, when snow reached sea level and covered many of our cities (thoughtfully doing so during a national holiday rather than on a busy workday!). After two winters of lockdown due to the COVID-19 pandemic, Italians were finally enjoying snow at its best.~~

Unfortunately, the season did not proceed as we hoped, and this wet start gave way to a prolonged, and similarly unusual, dry and warm period. Due to a persistent barrier of warm air on the western Mediterranean Sea (meteorologists call it a high-pressure ridge), almost no precipitation fell in northwestern Italy between mid-December and March, with only a couple of short storms in mid-February and mid-March providing limited relief. Meanwhile, warm, strong wind coming down off the Alps caused unseasonably high temperatures and largely melted the mountain snowpack. By the end of March, snow levels on the Italian Alps were 60% lower than the average of the previous 12 years (2010-2021, Figure A1)[1]. Water use is at its minimum during winter, so many Italians did not quite realize what was going on, and – importantly – what was about to unfold.

Spring and summer came like a wake-up call. Early loss of snow and the lack of rain quickly led to some of the lowest streamflow levels in recent history across the agricultural and industrial plains of the Po River (Figure A1). The river, a constant presence that many Italians respect and sometimes even fear during floods, was now just a slow, faint tickle, barely reaching its own outlet into the Adriatic Sea. Meanwhile, newspapers started using a word that many Italians were not prepared to hear, or handle: *drought*. With media coverage also came uncertainty and puzzlement, given how few of us were familiar with this creeping disaster: what happened to all that snow we started off with? What are we supposed to do now? How long will it last?



Place Moulin, June 2021 (left) vs. June 2022 (right) (c) ESA Copernicus

Two key features of the 2022 Italian drought, a marked deficit in snow cover (upper panel, Place Moulin in Aosta valley, June 2021 vs. 2022) and low streamflow (lower panel, Po river at Cremona). Credits: European Union, Copernicus Sentinel-2 imagery.

Then came emergency measures, like reducing irrigation water and releasing stored water from Alpine lakes[1]. In a country with millennia of fragmented history, these measures exacerbated endemic issues around who has the right to use water first and why. In our Mediterranean climate, the bulk of precipitation comes in fall through spring, meaning that drought conditions

[1], last access 04/09/2022

[1], last access 04/09/2022

~~are likely to linger at least across summer and early fall. So here we are, in early July 2022, in somewhat uncharted waters, facing at least a few more months of drought[1].~~

~~And yet, what seems like uncharted waters for Italians is vivid and growing reality in another part of the world. Between 2012 and 2016, California experienced a similarly intense snow and precipitation drought, caused by a high-pressure ridge sending storms north towards the Pacific Northwest rather than the Golden State (Californians called it the "Ridiculously Resilient Ridge"). Drought and low-snow conditions returned to the state in 2020 and show no signs of relenting – a new normal for the U.S.'s largest economy[1]. The full effects of the current dry period will not be known for years, but these certainly include a spike in tree mortality, a rise in wildfires, and expectedly severe water deficits. Events precipitated in 2015, when the then governor – Mr. Jerry Brown – issued an executive order mandating a 25% reduction in water consumption across the state. As allocations across farmers, municipal users, ecosystems, and industries were becoming increasingly contentious, California also passed landmark laws like the Sustainable Groundwater Management Act to protect groundwater from future non-sustainable use.~~

~~What California learned during the 2012–2016 drought is the same lesson that Italy is now learning the hard way – one that will characterize the whole 21st century: warmer temperatures (and occasionally less precipitation) could lead to less snow, less water, and ultimately more conflicts.~~

1 Introduction

Climate change is the big elephant in the room of our times. Fueled by anthropogenic emissions of greenhouse gases, climate change "has caused widespread adverse impacts and related losses and damages to nature and people, beyond natural climate variability" (IPCC, 2022). These impacts include an increase in heatwaves and extreme precipitation, an increase in human and tree mortality, wildfires, ocean acidification and sea level rise, damages to ecosystems, and reduced food security (IPCC, 2022). While some steps have been taken since the seminal United Nations Framework Convention on Climate Change in Rio de Janeiro (1992), and while attention ~~by~~ from the public has increased thanks to ~~bottom-up~~ initiatives like Fridays for Future, the United Nations Sustainable Development Goals, or the Sendai Framework for Disaster Risk Reduction, "most observed adaptation is fragmented, small in scale, incremental, sector-specific, designed to respond to current impacts or near-term risks, and focused more on planning rather than implementation" (IPCC, 2022). Current consensus, both at scientific and societal level, is that challenges related to climate change mitigation and adaptation will characterize the world for several generations to come ~~(Hardy, 2003)~~(Hansen et al., 2013; Zhenmin and Espinosa, 2019).

If climate change is the elephant, then the most proximal resource to humans and ecosystems – water – is the floor over which the elephant is standing. A rise in temperature as predicted by climate-change scenarios will lead to an increase in drought episodes (Spinoni et al., 2018), a rise in extreme events (Alfieri et al., 2017), a decline in snow water resources (Mote et al., 2018; Musselman et al., 2021), glacier depletion ~~(Shannon et al., 2019)~~(Bongio et al., 2016; Shannon et al., 2019), an imbalance between water demand and availability ~~(Barnett et al., 2005)~~(Barnett et al., 2005; Immerzeel et al., 2020), and ulti-

[1] ~~, last access 14/09/2022~~

[1] ~~, last access 04/09/2022~~

mately profound alterations in the whole water cycle (IPCC, 2022). Given the extent and intensity of human water management, such changes ~~will~~ may ultimately reflect into social instability, conflicts, poverty, displacement, and less water security at global scale (Kelley et al., 2015; Galli et al., 2022). This is particularly true where precipitation is highly seasonal and/or where snow and glaciers play a fundamental role in storing water during wet and cold winters to release it during warm and dry summers (Barnett et al., 2005). ~~Such socio-hydrologic processes have already taken place in human history: examples are the Dust Bowl drought in the US Great Plains (likely the worst drought episode of the last millennium in the U.S., Cook et al., 2014), or the fall of the Maya civilization as driven by water scarcity (Kuil et al., 2019). These episodes demonstrate that changes in the water~~ Changes in the water cycle will inevitably challenge our societies, ~~and that these three spheres –~~ since the water cycle, ecosystems, and human societies ~~–~~are and always will be intimately connected.

Despite these intimate connections, contemporary geosciences and, by reflection, water education from elementary to high schools often remain anchored ~~to~~ in a traditional view of the water cycle as a physical process where humans have little to no role. Meanwhile, surveys from various parts of the world show that ~~current high school students ' environmental literacy may be inadequate (Wardani et al., 2018)~~students tend to confound mitigation and adaptation to climate change with unrelated environmental issues (Bofferding and Kloser, 2015), while knowledge gained at school often does not translate in everyday habits (Amahmid et al., 2019) ~~. These difficulties may be related to the frequent issue of confounding mitigation and adaptation to climate change with unrelated environmental issues (Bofferding and Kloser, 2015), or simply to the very essence of climate change being an implausible, complex, and crossing-borders systemic risk (von Elverfeldt, 2022).~~ due to current high school students' environmental literacy possibly being inadequate (Wardani et al., 2018). These experiences speak for ~~an urgent need to reinvent~~ a need to expand how climate change education is done (Harker-Schuch and Bugge-Henriksen, 2013), as ~~for example~~ acknowledged by UNESCO[1].

~~We present~~ The overarching objective of this paper is to introduce the method of "Water and Us", an educational initiative developed by CIMA Research Foundation (Italy) to ~~respond to these challenges by focusing~~ engage scientists and teachers to co-deliver lectures on three topics: the natural and anthropogenic water cycle, climate change, and emerging water conflicts. The ~~general hypothesis behind Water and Us is that educating next generations on water resources management will not only raise their awareness, but also neutralize maladaptation, conflicts, and tensions through better policies and decisions – both in the long run, because studentswill be more informed citizens, and in the short term, because feedback provided by students can make an helpful contribution to inform current climate change adaptation policies.~~ initiative aims at filling knowledge gaps on the important, but often poorly understood link between water resources and security, climate change, and institutional governance. In so doing, we aim at both raising students' awareness on the escalating impacts of changes in water cycle on their own future, but also at stimulating their interest in these topics for personal study. Water and Us is an interdisciplinary initiative bringing together hydrologists, jurists, and communication experts, and is strongly committed to cross borders within and across scientific fields of study to modernize water education in a warming climate.

The paper is organized as follows: Section 2 introduces the educational approach of Water and Us, with particular emphasis on the three modules for high schools and their counterparts for elementary schools and adults. Section 3 discusses the array of

[1]https://en.unesco.org/themes/water-security/hydrology/water-education, last access 04/09/2022

metrics we are identifying to evaluate this approach and some early findings in this regard. Finally, Section 4 draws conclusions.

2 The educational approach

In describing the current method of Water and Us, we will inevitably refer to our specific experiences in Italy – see the example of storytelling in the Appendix regarding the Alpine 2022 drought. However, the approach described here is fully transferable, with Chapter 4 of the IPCC Assessment Report 6 on Water providing a general framework to identify emerging risks for a given location and how these risks link to governance challenges (see https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_Chapter04.pdf, last access 08/05/2023). The authors are also available to share all the materials used, including waterscape pictures (see Section 2.3).

The primary target audience of Water and Us is high-school students ~~,~~ (in Italy, 14 to 19 years old), but the offer has already been adapted for elementary schools and adults. The ~~main~~ choice of high-school students was due to two main factors. The first is the clear fit between this initiative and high-school programs in Italy. In this regard, Water and Us directly contributes to civics (in Italian, Educazione Civica, see https://www.istruzione.it/educazione_civica/), which includes educational targets on sustainability and environment awareness, and to science programs, which include chapters on the Earth system, the water cycle, and climate. The second is the symbolic leverage of high schools including the last step of mandatory education in Italy, which means that high-school students are in the process of deciding their own future when they are exposed to Water and Us, an aspect that promotes engagement and awareness.

The main structure of the initiative resolves around three objectives, four didactic pillars, and three modules (each needing 1.5 to 2 hours)~~, with four didactic pillars~~. Figure 1 summarizes these pillars and the content of each module.

2.1 Objectives

The main educational objectives of Water and Us are as follows:

1. inform next generations on the concept of "water resource" as an intertwined result of the natural water cycle and anthropogenic actions, and on how, where, when, and by whom water is used, transported, stored, and diverted in the Anthropocene;

2. educate students on the most salient aspects of climate change and its governance, including the difference between mitigation and adaptation, the role of international agreements, the scientific foundation of global warming, and how these processes can affect water availability at all scales – including future scenarios of water supply, floods, and droughts;

3. raise awareness on existing and potential governance conflicts around the use of water, especially in a warming climate, and on solutions for a nonconflictual water resources management.

These objectives are well nested into the Sustainable Development Goals, and in particular to #4 (Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all – Target 4.7 on ensuring that all learners acquire the knowledge and skills needed to promote sustainable development), #10 (Reduce inequality within and among countries – Target 10.2 on empowering and promoting the social, economic and political inclusion of all), and #13 (Take urgent action to combat climate change and its impacts – Target 13.1 on strengthening resilience and adaptive capacity to climate-related hazards and natural disasters in all countries).

2.2 Didactic pillars

From a methodological standpoint, Water and Us leans on four overarching pillars (Figure 1).

The first is an educational approach based on storytelling, under the assumption that the ancestral attraction of humans towards tales will gain their attention and enhance understanding. This first pillar goes well beyond "telling anecdotes": instead, it nests itself in a broad body of empirical and theoretical literature in education showing that storytelling can significantly reduce depersonalization, develop identities, promote empathy and diversity, aid with understanding of complex issues by linking them to the proximal world experienced by students, and ultimately generate new knowledge (Abrahamson, 1998; Collins, 1999; Haigh and Hardy, 2011; Hibbin, 2016; Astiz, 2020). In doing so, Water and Us seconds the advent of digital devices and so digital storytelling to generate vivid experiences for students through the mixture of voices, images, and videos (Robin, 2008). Note that our stories focus on contemporary events, such as ~~the California and Italian droughts~~ ongoing droughts across the world, rather than traditional tales (see the ~~Prologue~~ Appendix for an example).

The second pillar are hands-on experiences, ~~including role games,~~ to immediately put theory learned into practice. During our events, for example, students are asked to identify potential water stakeholders in familiar and less familiar landscapes, and then to impersonate these stakeholders in focus groups to reflect upon their needs with regard to water and how these needs may conflict (or be in synergy with) other stakeholders. Groups are finally asked to openly discuss these findings in an effort to tackle emerging conflicts and maximize synergies (see Section 2.3 and 2.5). Thus, we openly link Water and Us to the long-standing educational tradition of "learn by doing" (Schank, 1995) to go beyond the artificial setting of school education and allow for a more natural, immediate understanding of the subject matter.

Learning by doing is connected to the third pillar, which is a flipped classroom environment in which students become the protagonists of the teaching experience. To this end, ~~modules~~ each module in Water and Us ~~include both stories and~~ includes workshops led by the students for the students. In this framework, storytelling introduces the minimum amount of knowledge required by students to conduct the workshops themselves (lack of preparation being a frequent problem with flipped classrooms, Akçayır and Akçayır, 2018). While relatively new, this flipped classroom approach has already been widely applied, with proven benefits (Awidi and Paynter, 2019).

The fourth pillar is a constant link to the real world, and in particular to the most pressing, contemporary societal issues – water security and climate change. ~~We do so by bridging the gap between the traditional, geoscience-based approach to climate-change narrative and a more society-oriented framework including policy and governance.~~ The hypothesis here is that focusing on the real world will make topics covered by Water and Us more tangible and so more interesting to students, as

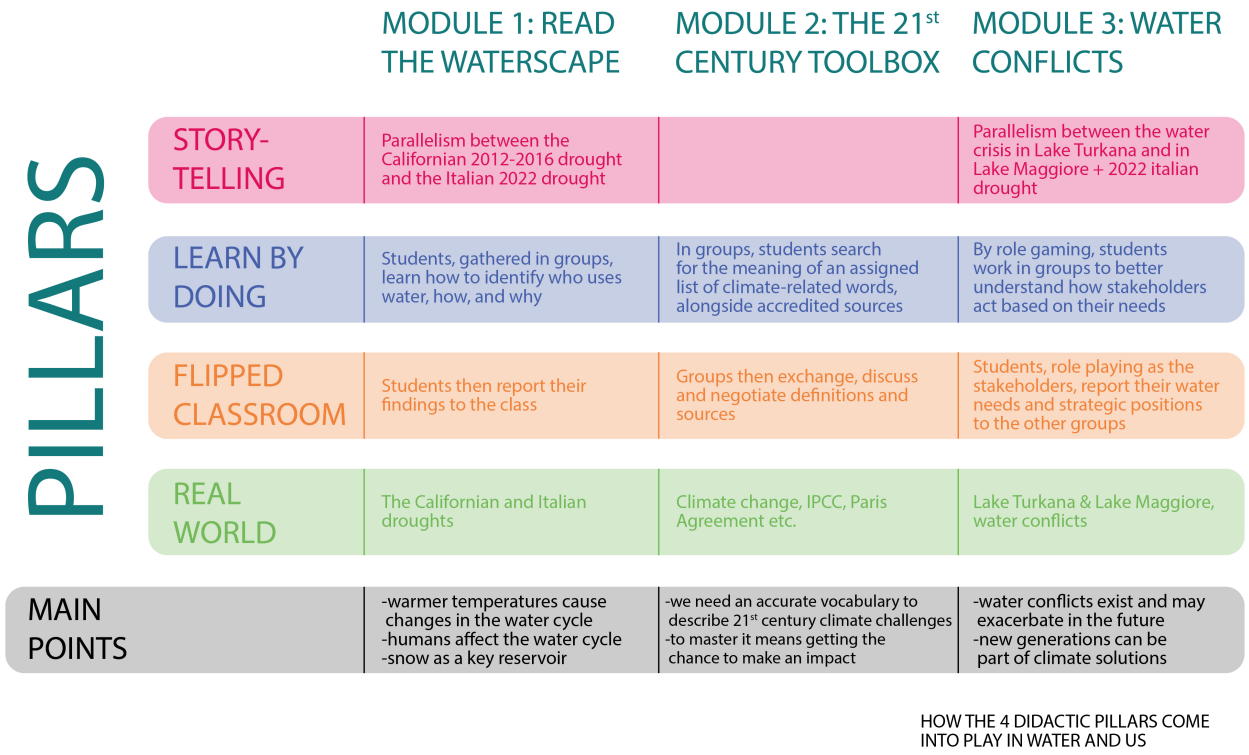


Figure 1. The four overarching pillars of Water and Us (first column) and how they come into play in the three educational modules.

they can directly relate to their future in a climate-change 21st century. This is in line with existing literature showing that climate-change education must be accessible and action-oriented ~~(Lee et al., 2013).~~ (for example, see Lee et al., 2013). In this regard, Water and Us synthesizes a geoscience-based approach to climate change with policy and governance, in an effort to make this initiative open to all aspects of water in the modern era.

2.3 Module 1: read the waterscape

Starting from the four didactic pillars outlined above, the first module of Water and Us ~~is all about~~ focuses on the water cycle in a warming climate (Figure 2). This module builds from the ~~intuition~~ premise that water is an essential resource for life on our planet to make three broader points. First, that the natural water cycle of evaporation – precipitation - runoff is now part of a much broader and more complex mechanism including regulations, allocations, and demands by human societies, which can significantly change the natural course of water across our planet and introduce a striking variety of water stakeholders (Sivapalan et al., 2012). Second, that in temperate regions of the world ~~like Italy~~ this natural/anthropogenic water cycle relies on an intermediate natural reservoir, snow, which is often overlooked and rarely seen as a key precondition for life on our planet

(Barnett et al., 2005). Third, that this natural/anthropogenic water cycle is changing, due to a recurring pattern in temperate regions of warmer temperatures, less snow, and eventually less available water (IPCC, 2022).

Figure 2. Some content from Module 1 of Water and Us: students learning how to read the waterscape (who is using water, where, and why?) and an iconic image of the California snow drought (then Governor Jerry Brown taking part in the 2015 Snow Survey at Phillips Station, the first with no snow on the ground in April– credits: CA Department of Water Resources).

We originally chose to make these points by linking future scenarios of temperature, snow, and water supply in Italy with an exemplary story from another part of the world, the California 2012-16 snow drought ~~(see Harpold et al., 2017, and the Prologue above)~~ (see Harpold et al., 2017, and the Appendix). By showing real-world implications of the link between warmer temperatures, less snow, and less water, the California drought is a perfect ~~archetype~~ example of the challenges posed by global warming and increased aridity for the natural/anthropogenic water cycle we live in. ~~This story was made particularly vivid by the fact that one of the coauthors (acting as storyteller) lived in California for a couple of years in the immediate aftermath of the drought.~~

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Our events started in January 2022 ~~(see the Results section below)~~ and so we soon had to re-adapt this framework to include the unfolding Italian drought (see the ~~Prologue~~Appendix). We made the pragmatic choice of preserving the California story, but progressively included ~~parallelisms to the concurrent~~ parallels to the 2022 Italian temperature and precipitation anomalies, snow deficit, and streamflow lows. We found that doing so enhanced credibility of our stories as students appreciated patterns across continents and were able to find links to topics that were covered by media and social networks at the time. Albeit unfortunate in nature, this coincidence of events made Water and Us concrete and relevant to students.

The ~~first module~~ focus on droughts was instrumental, as it allowed us to link Water and Us to our own experiences related to climate change and water and thus make communication more effective for our audience. We acknowledge that other water risks may be relevant to different contexts, cultures, and representations of what is at stake, such as sea level rise (Cazenave et al., 2014), emerging flood pressure (Hirabayashi et al., 2013), shrinking glaciers endangering mountain communities (Council et al., 2012), or increasing desertification (Stringer et al., 2009). Even maintaining a focus on droughts, we highlight

that other episodes can be useful to contextualize local events in a global framework, such as the multi-year drought in the Andes (Rivera et al., 2017) or in Australia (Saft et al., 2015). The key ingredient of this first module is the focus on nature-human interactions around the use of water, and how these interactions are challenged in a warming climate.

The first module always ends with a ~~laboratory~~workshop, dedicated to putting gained knowledge about the natural/anthropogenic water cycle into practice. We gather students in small groups (4 to 5 maximum members), assign one landscape to each of them (see an example in Figure 2), and ask students to pinpoint who is using water, how, and why ~~. In a few words, students are asked to~~ – students thus train themselves to read the waterscape. Students are left with approximately 15 minutes to accomplish this goal, and are asked to write their notes on sticky notes that are then placed on their waterscapes. At the end of this work, students report their findings to the class and come up with a bottom-up, shared categorization of recurring water stakeholders. We found this to be particularly important not only because knowledge of water stakeholders is a precondition to understand following modules in Water and Us (and more generally what is at stake regarding water security in a warming climate, see ~~module 3~~Section 2.5), but also because most high-school students we interacted with reported that the last time they were taught about the water cycle was in elementary school.

2.4 Module 2: the 21st-century toolbox

The second module focuses on climate change, a term that is well known to students but that – often – few are able to clearly explain. This gives us an opportunity to convey two main messages: 21st-century challenges have a precise and accurate vocabulary and handling this vocabulary is a precondition for next generations to play an impactful role in shaping the future. At the same time, information that can be gathered from current media can be inaccurate, or simply partial. This second module of Water and Us aims at going from such incomplete definitions to a coherent picture of ongoing climate-change debate at global scale.

Different from module 1 and 3, module 2 is entirely based on a ~~laboratory~~ workshop (Figure 3). Students are again shuffled into small groups and are assigned a list of terms related to climate change, such as “global warming”, “IPCC”, “COP21”, “sustainability”, “greenhouse gases”, “mitigation and adaptation", or “Paris Agreement”. We then ask students to use their own knowledge and digital devices to come up with an accurate, and yet concise definition of each of these terms. While doing so, we ask them to check for multiple sources, note down these sources, and discuss how and why definitions may differ across them. After this first round, ~~students negotiate definitions across groups and sources to~~ each group of students is asked to explain their definition to the class to not only improve ~~their own~~ shared knowledge, but also potentially compare definitions across groups and so realize the quality of accredited and independent sources~~(especially on the internet)~~.

This ~~laboratory~~ workshop can be iterative, based on available time and feedback from students: for example, we often notice a particular interest from students about IPCC, and so go through a second round with words like “RCP”, “climate”, or “future scenarios” to second their interest in this sense. At the end of the ~~laboratory~~workshop, we encourage students to note down the final definitions for them to keep a toolbox for future use.

Figure 3. Some content from Module 2 of Water and Us: students proposing definitions of the most recurring terms related to climate change.

2.5 Module 3: water conflicts

Module 3 connects the dots between the previous two modules and focuses on the main societal implication of a changing climate in a natural/anthropogenic water cycle: emerging water conflicts. ~~Another "known" term with however unclear implications, we introduce water conflicts to make two broader points: first, these conflicts exist and will be exacerbated in a warming climate (Kelley et al., 2015); second, that solutions to these conflicts are there, and students could take part to these solutions.~~

Discussing water conflicts with Italian students may ~~apparently~~ be challenging, because they tend to associate these matters ~~to~~ with more arid regions of the world. To overcome this issue, we break down our story in two parts. The first is indeed quite exotic for our audiences and ~~regards~~ deals with the water crisis concerning ~~the mismanagement of~~ Lake Turkana and how it is associated to climate variability (Yongo et al., 2010). For our audience, this has the classical setting of water crises as they expect them. We then move to a much less known situation, the transnational management of Lake Maggiore across Italy and

Switzerland and how it is exacerbated by ongoing climatic extremes (Guariso et al., 1985). We show how national resolutions on lake level have already led to court decisions or tensions across stakeholders, and how these tensions are indeed seeds of potential, future water conflicts. Here again, the mounting 2022 Italian drought gave us an unfortunate opportunity to bring newspapers and media coverage to classes and discuss concrete examples of these seeds, such as public conversations on who was the priority water user, or how and when to divert water from one river to another for drought relief.

We end module 3 with a role game, where each group of students chooses one category of water stakeholders as they were identified during module 1 (~~e.g., agriculture~~ the most recurring ones being the agriculture sector, industries, civil water supply, ecosystem conservation, hydropower, or tourism). Each group is ~~then~~ first asked to reflect on their specific need concerning water (when and where do we need water? Why do we need it?) and what ~~are the~~ decisions they would like society to make in their own interest (e.g., some stakeholders may want little to no water restriction, while other stakeholders may be in favor of specific water infrastructures). After reporting these needs and positions to the other groups, ~~we work with students~~ groups gather again to identify what are the strategic positions ~~each stakeholder~~ they can take to achieve their needs and what positions may, instead, represent a seed of conflict (e.g., some economic sectors may second ecosystem conservation, but may dislike priority allocation to other sectors, and so forth, Figure 4). ~~We do so by asking students to focus on their neighborhood, in order both to hammer down this laboratory into their own experience and so facilitate discussion, and to show that water conflicts are no exotic thing but, rather, very proximal to them in a warming climate.~~ This workshop ends by summarizing potential conflicts and synergies on a poster (see Figure 4), which remains to the class as another deliverable of Water and Us in addition to waterscapes and the climate-change vocabulary discussed in the previous sections.

2.6 Elementary students and adults

Adapting Water and Us to elementary schools ~~required identifying the most significant messages to be transmitted and the most effective means of communicating with children. We came up with~~ (6-11 years old) required rethinking the structure and content of the program to identify a set of messages that were both effective to communicate to children and in line with the overall concept of this initiative. We thus selected three core messages related to the importance of water sustainability: first, water is the most precious resource on Earth, because we all need it to live; second, water must be preserved and not wasted; and third, we are not the only ones needing water. ~~Note that these three messages capture the essence of the three modules of the high-school version of Water and Us.~~

From a methodological standpoint, the elementary edition of Water and Us consists of one module, of approximately 2 hours. We start with brainstorming around three questions: where does water live? What do we need water for? Who uses water? The answers to these questions are noted on the blackboard and remain visible throughout the event, as they will be used in a third step to reorganize students' knowledge of the natural and anthropogenic water cycle (Figure 5).

The second step involves telling a story to students while they look at iconic images drawn in color on large card-boards (see Figure 5). The story is about a child who becomes a friend of water through the typical "ups and downs" of child relationships: they initially enjoy playing together, but soon start to play pranks on each other (for example, the child wastes or pollutes water, while water takes revenge with flooding). At the end of the story, children become aware that water is their closest friend ~~("how~~

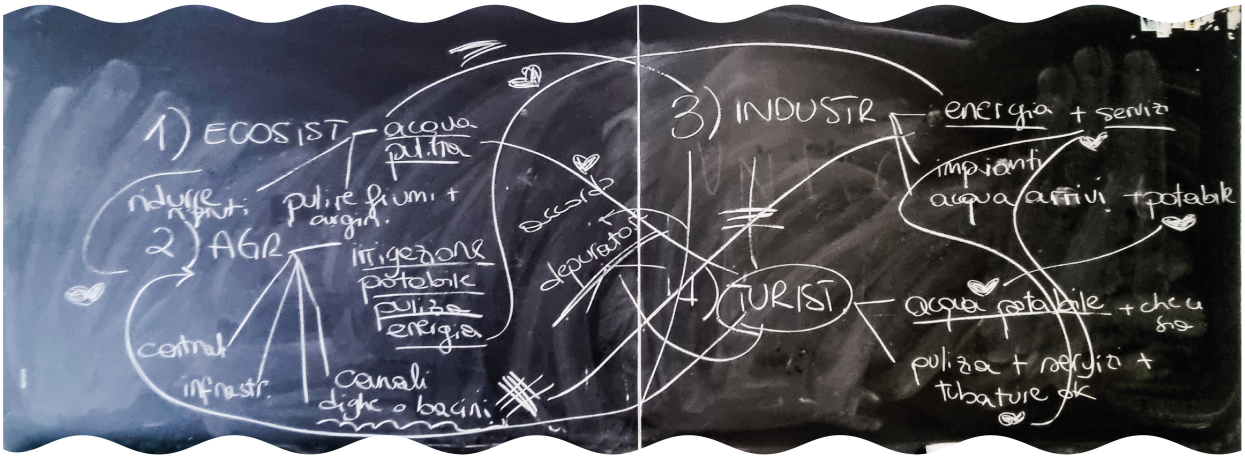

Figure 4. Some content from Module 3 of Water and Us: a map of water stakeholders (industries, ecosystems services, agriculture, tourism) and potential synergies-competitions.

~~can you be an enemy of something that makes up 70% of yourself?").~~ as it follows them in all aspects of their everyday life. The concept, structure, and development of the story are all geared towards getting students to relate to this story, while seeing parallels with their daily friendships. This story is also available upon request.

The final step is to involve students in a drawing workshop: they represent situations in which they have been friends of water and, on the other side of the sheet, situations in which they have been enemies of water. In doing so, we stimulate causal discussions to get feedback and reinforce their learning of core messages.

Adapting Water and Us for adults is still work in progress. As of today, our main experience has been with traditional seminars or lectures to professionals or philanthropic organizations about water, climate change, and conflicts. Despite being more conventional in structure and development, we do preserve the central role of storytelling with adults. Here again, our experience is that starting from real-world stories, such as again the California drought or Lake Turkana, is an effective way of conveying upper-level concepts like climate change and sustainability.

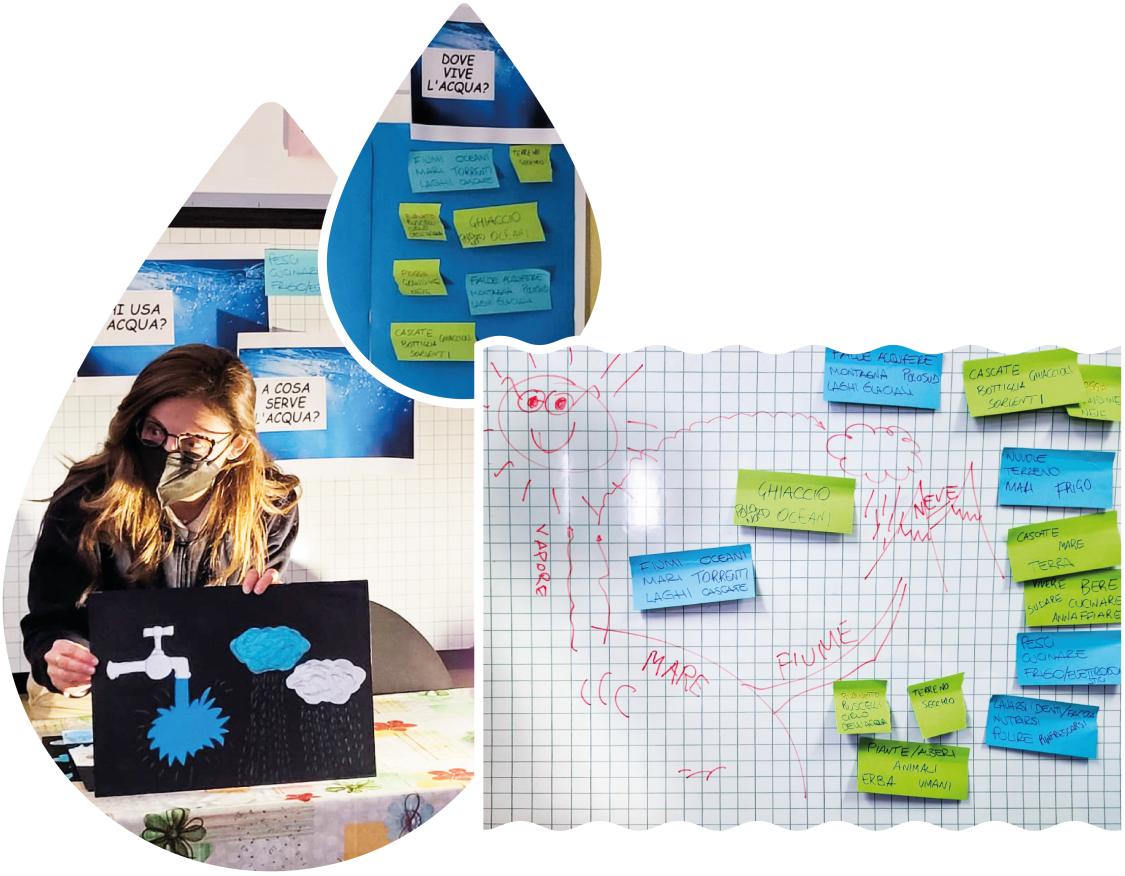

Figure 5. Snapshot from the elementary-school edition of Water and Us, where students are engaged through a dramatization of a fictional friendship between a child and Water.

3 Pathway to impact

Water and Us was established in autumn 2021 and worked as a proof of concept during the 2021-22 school year. The goal of this first phase was to develop the main portfolio of activities~~and~~ , to test it in the real world with small-scale experiments~~. In doing so, we also identified measures to~~ , and to leverage these experiences to identify indicators to validate the method and capture its impact. This phase involved 3 schools, 200+ students and 100 adults, and 40+ hours of events. In this section, we elaborate on these ~~measures by following the European Commission's Horizon Europe breakdown in societal, scientific, and technological impacts~~experiences and how they informed an array of proposed indicators (see Table 1).

3.1 ~~Societal impacts~~

Objective	Indicator	Monitoring Method
Objective #1	Average/variance # of water stakeholders identified on waterscapes	Sticky notes
	Average/variance # of identified seasonal data for water stakeholders on waterscapes	Sticky notes
	# of students with prior knowledge of the water cycle	Questionnaire
	# of students with prior knowledge of the human aspects of the water cycle	Questionnaire
Objective #2	Average/variance # of students with pre/post awareness of climate change	Questionnaire
	Average/variance # of students with pre/post awareness of IPCC	Questionnaire
	Average/variance # of students with pre/post awareness of the Paris Agreement	Questionnaire
Objective #3	Average/variance # of identified synergies across water stakeholders	Sticky notes
	Average/variance # of identified conflicts across water stakeholders	Sticky notes
	Average/variance # of identified "collaborators" across water stakeholders	Sticky notes
General impact	Number of students involved	Organizers' data record
	Number of teachers involved	Organizers' data record
	Number of schools	Organizers' data record
	Number of hours	Organizers' data record
	Percentage of audience in elementary schools	Organizers' data record
	Percentage of audience in high schools	Organizers' data record
	Percentage of audience in non-student positions	Organizers' data record
	Percentage of students taking part to all workshops	Organizers' data record
	Number of schools per year requesting new editions of Water and Us	Organizers' data record
	Number of schools per year requesting follow-up editions of Water and Us	Organizers' data record
	Number of PCTO programs associated with Water and Us	Organizers' data record
	Number of career-related follow-up questions by students	Organizers' data record

Table 1. Proposed set of indicators to measure the impact of Water and Us. PCTO means "Paths towards Cross-cutting Skills and Orientation" (in Italian, Percorsi per le Competenze Trasversali e per l'Orientamento, see Section 3).

~~From a societal perspective, Water and Us directly addresses EU policy priorities regarding climate-change education and sustainability, as for example envisaged in the NextGeneration EU program, and strengthens the uptake of research and innovation in society by creating educational opportunities for studentsto engage directly with researchers and learn about the most recent findings in water science-policy and climate change. Beyond European goals, the spirit and ambitions of Water and Us are well aligned with the UN Sustainable Development Goals and in particular goal~~ Regarding objective ~~#4 (Quality Education) , #10 (Reduced Inequalities), and #13 (Climate Action)~~1 ("inform next generations on the concept of "water resource", as an intertwined result of the natural water cycle and anthropogenic actions, and on how, where, when, and by whom water is used, transported, stored, and diverted in the Anthropocene"), we found the workshop on identifying water users on waterscapes to be particularly effective as a measure of students' prior knowledge of the water cycle and water

stakeholders (see Figure 2). As such, we propose using the average and variance of the number of water stakeholders identified on these waterscapes across groups as a concrete measure of the effectiveness of module 1 in communicating the complexity of the anthropogenic water cycle in the modern era. The average and variance of the number of temporal aspects that each group was able to attach to stakeholders (when do they need water?) could also be used to further shed light not only on water users, but also on how their needs intersect with each other in time. Based on our initial experiences, we also propose submitting an informal questionnaire to students at the beginning of these workshops to measure how many students were already aware of the concept of water cycle and/or of human interventions in it.

~~We preliminarily measured this impact through a standard array of top-down indicators: Number of involved students : 200+, divided into ~120 elementary-school students and ~110 at~~ The questionnaire could also be leveraged to measure prior and a-posteriori awareness of students regarding climate change, and thus as an indicator of objective #2 ("educate students on the most salient aspects of climate change and its governance, including the difference between mitigation and adaptation, the role of international agreements, the scientific foundation of global warming, and how these processes can affect water availability at all scales – including future scenarios of water supply, floods, and droughts"). Our initial experience qualitatively confirmed that awareness of climate change among high-school ~~level; Number of schools: 3, all based in Liguria (Italy); Number of involved adults: ~120, based between Liguria and Lombardia (Italy); Number of hours of events: ~40 hours of events.~~

~~We also identified two bottom-up indicators of societal impact. The first one entails asking teachers to grade our laboratory in the context of existing school programs. From this standpoint, 100% of teachers found the content interesting and in line with their syllabus. The second one measures the knowledge of climate-change terms among students at the beginning of the course~~students is high (we use the word "qualitatively" here to denote that these results were not based on the indicators proposed in Table 1 and are thus to be interpreted as soft data). This finding is in line with the existing literature on this matter, such as Jürkenbeck et al. (2021) or Kuthe et al. (2019). At the same time, we noted recurring difficulties in students to spell out what climate change exactly is, and particularly what society is doing in this regard. As a result, we propose to explicitly monitor through a questionnaire the prior and a-posteriori knowledge of terms like "climate change", "IPCC", and "Paris Agreement" as an indicator of student's awareness of the (often cumbersome) decision process characterizing adaptation and mitigation. In this regard, ~~it strikes~~ our preliminary work showed that only 20% and 10% of questioned students knew about the IPCC and the Paris Agreement before the course, respectively. On the other hand, 90% of them had already heard about climate change.

3.1 ~~Scientific impact~~

~~From a scientific standpoint, Water and Us primarily fosters diffusion of knowledge across all generations.In this regard, 31% of our audience has been elementary-school students aged 8-11; 35% has been high-school students aged 16-19, while 34% has been adults aged 30+.~~

Achieving objective #3 represents the essential outcome of the whole process ("raise awareness on existing and potential governance conflicts around the use of water, especially in a warming climate, and on solutions for a nonconflictual water resources management."). Here again, the hands-on workshop provide concrete indicators to measure this gained awareness:

we propose quantification through the average/variance number of identified synergies, conflicts, and "collaborators" across water stakeholders – as emerged across groups. Comparison across geographic locations as Water and Us ~~also strengthens human capital in research and innovation and creates high-quality new knowledge, particularly at the intersection of hydrology and water policy and governance. This initiative thus contributes to the emerging and cross-disciplinary scientific field of socio-hydrology, which promises to shed new light on how humans interact with the environment and particularly the water cycle (Sivapalan et al., 2012; Di Baldassarre et al., 2019). Preliminary impact indicators in this regard include, e.g., one paper on international peer reviewed journals (the present paper) and one conference at EGU 2022 (Munerol et al., 2022).~~ progresses will allow to draw a clear picture of how such tendency to synergies or conflicts change with time and space, especially as extremes emerge in a warming climate.

3.1 ~~Economic and technological impact~~

~~While educational in essence,~~ We finally propose a set of monitoring indicators to measure the overall impact of Water and Us in terms of involved students, teachers, and schools, as well as involved ages (see again Table 1). We also propose to monitor the number of students who take part to all modules and the number of schools asking for repetitions of Water and Us through school years as further measures of the impact of this program across years and across modules. Since Water and Us ~~has the potential to leverage investment in research and innovation, generate innovative ideas, and promote employability of future generations. In this regard, we identified two suggestive indicators during this first year of events.~~

~~First, 25+ high-school students asked for more information on our work at CIMA Research Foundation. The most recurring question in this regard was: "what did you study at university to know about this?". We see this indicator as a proxy of students' interest in engaging in scientific disciplines, rather than a specific interest in our organization.~~

~~Second,~~ also represents an opportunity for students to be exposed to the job market through the concrete topics discussed in the workshops, we finally propose to include as additional indicators the number of career-related follow-up questions by students, and importantly the number of schools that officially included Water and Us in their career-preparation portfolio. This was the case for one of our high-school events~~was officially~~, which was contextualized in the so-called "Paths towards Cross-cutting Skills and Orientation" (in Italian, Percorsi per le Competenze Trasversali e per l'Orientamento – PCTO). Established at national level by law 145/2018, PCTOs promote the development of soft and career-oriented skills in high-school students by exposing them to the job market in controlled environments. This framework did not modify the ambition and overall organization and spirit of Water and Us, but at the same time provided us with the opportunity to explicitly discuss with students about job opportunities related to climate change and science (Figure 6).

4 ~~Lessons learned and future directions~~

~~Working in close contact with a variety of audiences and contexts not only gave us encouraging early results (as outlined in Section 3 above), but also several helpful lessons for the future.~~

Figure 6. High-school students visiting CIMA Research Foundation to learn about floods during one of our Water and Us initiatives. This was an opportunity to discuss about employability in climate-change science as part of a "Paths towards Cross-cutting Skills and Orientation" (PCTO, see main text for details).

~~First, we confirm that awareness in climate change among high-school students is qualitatively high (see Section 3 above). This finding is in line with the existing literature on this matter, such as Jürkenbeck et al. (2021) or Kuthe et al. (2019). We also qualitatively confirm the breakdown of youngsters by Kuthe et al. (2019) in Charitables (well informed and behaving accordingly), Paralyzed (well informed but overwhelmed), Concerned Activists (highest level of awareness and proactive in informing others), and Disengaged (not informed and~~Water and Us is continuing in 2022~~/or not willing to act), even though we found a very small proportion of the fourth group (likely because some of our events in high schools were on a voluntary basis and this may have skewed the sample toward well informed students). At the same time, we noted recurring difficulties in students to spell out what climate change exactly is, and particularly what society is doing in this regard. We argue that more effort is needed to go beyond the classical, science-oriented framework of climate-change communication to also convey societal implications and the (often cumbersome) decision process characterizing them.~~

Second, we found that each audience has its own priorities, and what is relevant to scientists might be totally irrelevant to students, or vice versa. For example, we found students to be very interested in topics like pollution or desalination, both of which were unexpected to us and are not covered by our portfolio of Water and Us. Thus, while Water and Us is fully transferable to other settings, this finding suggests that tailoring it to a given audience is always needed. In this regard, Lee et al. (2015) show that the best predictor of climate change awareness varies with the geographic and socioeconomic context, and this specificity is crucial to make climate-change communication successful.

Third, we expectedly found that the most successful communication strategy always starts from conveying simple, clear, and consistent messages. This agrees with evidence that simplicity, rather than complexity, drives cognitive processes (Chater and Vitányi, 2003) . We followed this rule by focusing on four concrete measures: including take-home messages, relying on pictures rather than text, preferring real-world stories over theoretical explanations, and letting students take the lead (see the overarching pillars of Water and Us, Figure 1). Despite being intuitive, following this simple rule has initially proven challenging to researchers like us, as it requires a paradigm shift from our standard scientific communication style based on facts and references towards mining the essence of our message, and importantly why it is important. This finding confirms the need for improving communication skills in science.

Fourth, our experience shows that students are equally engaged by global and local issues, but these two categories respond to different interests and so should be leveraged with different goals. We (expectedly)found global issues to best work to attract students and "catch their attention", exactly because they are perceived as exotic and unusual. On the other hand, local issues are best suited as a call for action and so to translate knowledge gained with Water and Us into behavioral change. Therefore, we generally start our laboratories with global stories, which are then linked to local instances. These local stories can also be streamlined into 23, nested in several national and European projects dedicated to climate-change awareness and communication. A concrete example in this regard is I-CHANGE (https://ichange-project.eu/, last access 06/09/2022), where Water and Us was part of educational activities related to the Living Lab paradigm in Genova (https://ichange-project.eu/open-air-laboratory-in-genoa/, last access 06/09/2022). Regarding future steps, we remain interested in networking with interested partners to scale up this experience at an international level. This will necessarily need ways to adapt Water and Us to different audiences and cultures. We identified three promising resources and one pre-condition in doing so. The first resource is the already mentioned Chapter 4 of the IPCC Assessment Report 6 on Water (see Section 2). The second resource is the framework provides by UN Water (https://www.unwater.org/, last access 20/05/2023), including its section on water facts providing concrete examples of behavioral change, such as those promoted by Horizon Europe projects like I-CHANGE (water sustainability cases across the globe. The third resource is the UN Sustainable Development Goals (https://sdgs.un.org/goals, last access 0620/0905/2022). Importantly, this attention for behavioral change in local communities provided us with concrete opportunities to fund 2023), which also provide concrete examples of targets and metrics related to sustainability and climate change. The main pre-condition in scaling up and transferring Water and Us through participatory projects following the Living Lab paradigm (, last access 06/09/2022).

is that these new editions should be collaboratively led by local scientists, rather than the present authors. This is important to maintain one of the most promising aspects of Water and Us will continue in 2022/23, when it will be nested in several

national and European projects dedicated to climate-change awareness. In this regard, we storytelling and overall educational framework: it is about local students engaging with local scientists in knowing more about local and global notions. The present authors remain available to accompany and support interested colleagues in this process.

We also further aim to advance on concrete tools enabling students to make their voices heard in climate-change policy through Water and Us. This is important to improve the bottom-up aspect of this initiative and so allow students to inform our work as researchers in hydrology, policy, and governance. In order to achieve this goal, we envision are experimenting a fourth module of Water and Us where students propose concrete measures to tackle climate change, cluster in advocacy groups to promote their vision, and finally vote on each of these propositions. This will educate students to democracy and free speech, while allowing us to gather quantitative numbers to substantiate students' priorities and positions regarding climate change. We plan to document these findings in a follow-up paper.

4 Conclusions

We presented Water and Us, an awareness initiative geared towards contributing to educating next generations to in the challenges of water security and conflicts in a warming climate. Water and Us was established in 2021 and involved about 200 students and 100 adults across 40 hours of events in a first set of experiments in 3 schools to test the approach and validate it. We defined a repeatable structure for high schools made of three educational modules dedicated to the water cycle, climate change, and water conflicts. Water and Us affirms the value of storytelling and of learning by doing, while putting students at the center of a learning process made by hands-on laboratories. We will continue workshops. We are continuing the experience of Water and Us in 2022/23and are interested in networking with interested partners to scale up this experience at international level, as part of EU Horizon projects geared towards behavioral change and education.

Author contributions. All coauthors contributed to the initial design of Water and US. FM and FA developed the initial educational portfolio and tested it during the 2021-22 school year, with inputs from all coauthors. FM and FA prepared the first draft of this manuscript, with contributions from all coauthors.

Competing interests. Authors declare that no competing interests are present

Ethical statement

The work presented is original, reflects the authors' observations, and does not deal with sensitive data. The work presented respects what was stated in the Helsinki Declaration of 1964, the cornerstone of the ethics of human research. Ethical approval was requested and obtained from the body to which the authors belong.

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Appendix A: An example of storytelling – a tale of water and snow

Winter 2021-22 hit the ground running in Italy, with the first snowflakes falling across the Alps in early November. Snow returned between November and early December, when a second large storm hit most Italian mountain ranges. Early snowfalls peaked on December 8, when snow reached sea level and covered many of our cities (thoughtfully doing so during a national holiday rather than on a busy workday!). After two winters of lockdown due to the COVID-19 pandemic, Italians were finally enjoying snow at its best.

Unfortunately, the season did not proceed as we hoped, and this wet start gave way to a prolonged, and similarly unusual, dry and warm period. Due to a persistent barrier of warm air on the western Mediterranean Sea (meteorologists call it a high-pressure ridge), almost no precipitation fell in northwestern Italy between mid-December and March, with only a couple of short storms in mid-February and mid-March providing limited relief. Meanwhile, warm, strong wind coming down off the Alps caused unseasonably high temperatures and largely melted the mountain snowpack. By the end of March, snow levels on the Italian Alps were 60% lower than the average of the previous 12 years (2010-2021, Figure A1)[2]. Water use is at its minimum during winter, so many Italians did not quite realize what was going on, and – importantly – what was about to unfold.

Spring and summer came like a wake-up call. Early loss of snow and the lack of rain quickly led to some of the lowest streamflow levels in recent history across the agricultural and industrial plains of the Po River (Figure A1). The river, a constant presence that many Italians respect and sometimes even fear during floods, was now just a slow, faint tickle, barely reaching its own outlet into the Adriatic Sea. Meanwhile, newspapers started using a word that many Italians were not prepared to hear, or handle: *drought*. With media coverage also came uncertainty and puzzlement, given how few of us were familiar with this creeping disaster: what happened to all that snow we started off with? What are we supposed to do now? How long will it last?

Then came emergency measures, like reducing irrigation water and releasing stored water from Alpine lakes[3]. In a country with millennia of fragmented history, these measures exacerbated endemic issues around who has the right to use water first and why. In our Mediterranean climate, the bulk of precipitation comes in fall through spring, meaning that drought conditions are likely to linger at least across summer and early fall. So here we are, in early July 2022, in somewhat uncharted waters, facing at least a few more months of drought[4].

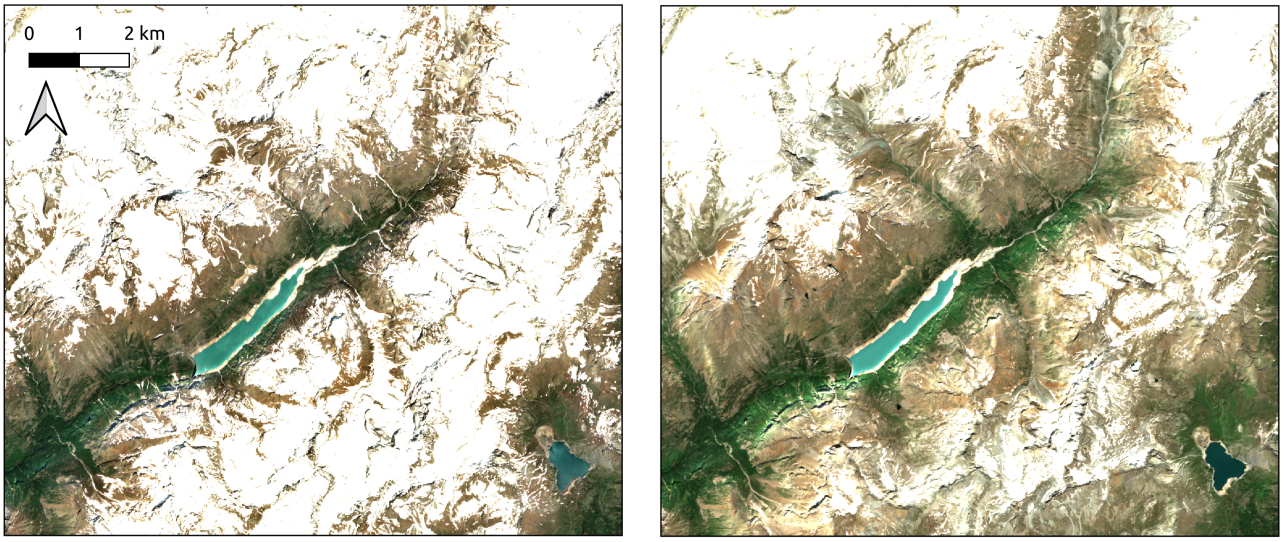
And yet, what seems like uncharted waters for Italians is vivid and a growing reality in another part of the world. Between 2012 and 2016, California experienced a similarly intense snow and precipitation drought, caused by a high-pressure ridge sending storms north towards the Pacific Northwest rather than the Golden State (Californians called it the "Ridiculously Resilient Ridge"). Drought and low-snow conditions returned to the state in 2020 and show no signs of relenting – a new normal for the U.S.'s largest economy[5]. The full effects of the current dry period will not be known for years, but these

[2] https://edo.jrc.ec.europa.eu/documents/news/GDO-EDODroughtNews202203_Northern_Italy.pdf, last access 04/09/2022

[3] https://www.adbpo.it/misure-definite-dallosservatorio-per-far-fronte-alla-crisi-idrica/, last access 04/09/2022

[4] https://edo.jrc.ec.europa.eu/documents/news/GDO-EDODroughtNews202208_Europe.pdf, last access 14/09/2022

[5] https://www.gov.ca.gov/2021/04/21/governor-newsom-takes-action-to-respond-to-drought-conditions/, last access 04/09/2022



Place Moulin, June 2021 (left) vs. June 2022 (right) (c) ESA Copernicus

Figure A1. Two key features of the 2022 Italian drought, a marked deficit in snow cover (upper panel, Place Moulin in Aosta valley, June 2021 vs. 2022) and low streamflow (lower panel, Po river at Cremona). Credits: European Union, Copernicus Sentinel-2 imagery.

certainly include a spike in tree mortality, a rise in wildfires, and expectedly severe water deficits. Events escalated in 2015, when the then governor – Mr. Jerry Brown – issued an executive order mandating a 25% reduction in water consumption across the state. As allocations across farmers, municipal users, ecosystems, and industries were becoming increasingly contentious, California also passed landmark laws like the Sustainable Groundwater Management Act to protect groundwater from future non-sustainable use.

What California learned during the 2012–2016 drought is the same lesson that Italy is now learning the hard way – one that will characterize the whole 21st century: warmer temperatures (and occasionally less precipitation) could lead to less snow, less water, and ultimately more conflicts.