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Future Water: A Multi-University International Web Seminar

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Abstract: Historically, water utilities have relied on tried-and-true practices in the design and operation of their infrastructure, tapping new resources and expanding networks as needed. However, as the effects of climate change and/or urbanization increasingly impact both water supply and demand, utilities need new, holistic planning and management approaches. Integrated planning approaches must account for changing policies, technological progress, and unique, setting-specific operating conditions. Based on this notion, an international web seminar with faculty, researchers, and students from nine universities across five continents was conducted. In the 3-month seminar, participants were split into groups and tasked with developing future-proof, sustainable water management solutions for fictitious settings with unique resource availability, climate change predictions, demographic, and socioeconomic constraints. The goal of the seminar was to combine participants' unique perspectives to tackle challenges in developing future water infrastructure, while forming lasting relationships. Water management concepts became more daring or "out-of-the-box" as the seminar progressed. Most groups opted for a holistic approach, optimizing existing infrastructure, integrating decentralized water management, furthering digitization, and fostering the adoption of innovative policy and planning strategies. To gauge their impact on the evolution of ideas, group dynamics and communication were observed throughout the seminar. As a result, the findings serve not only as a compendium of ideas and concepts for holistic design in the water sector, but also facilitate international collaboration, improve communication in cross-cultural teams or guide the development of training programs in water management for researchers, professional engineers, or water utilities.

Keywords: future water supply; smart water; sustainable infrastructure development; climate change adaptation; resilient water distribution systems; web seminar; cross-cultural collaboration; civil engineering education

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1. Introduction

Water utilities tend to be conservative in their approaches to the provision of water services and rely on tried-and-true methods for delivering critical resources to their customers. Major utility decisions have focused on the capacities of pipes and pumps over time and on the location and size of single centralized water and wastewater treatment plants to deliver water from reliable, sufficient sources to consumers, treat, and return effluent back to the environment.

New challenges are arising that have altered water planning and will continue to do so. Infrastructure planning is confounded by the uncertainty of: historic and continued depletion of water resources, climate change, absolute population and density growth or decline, water quality, recognition of environmental water demands, and budgets for upgrading and replacing aging infrastructure [1–4]. For many water providers, budget constraints resulting in historic under-investment in infrastructure maintenance are the most significant driver and impetus for change. In total, these disruptions will allow and/or force utilities to shift from traditional water supply alternatives to emerging methods [5,6] to provide reliable, resilient water management and systems.

Using an integrated water planning framework, Singapore is an exemplar of how adaptations can be applied in a more general context; including desalination and water reuse [7,8]. In Australia, a water market was seeded during the recent drought [9,10] as was a shift toward ocean desalination in its major coastal cities. In the face of population growth and diminishing supplies, US providers in the southwest have actively considered reclaimed water as the next bucket of water [11]. Recognition that water is reused in many locations [12]—either intentionally or de facto by downstream users—suggests that plans for clearly defining its water supply role are needed [13–15]. However, to tap its potential, reused water may require a new parallel infrastructure and water quality monitoring from sources to users. Some water planners have begun to adopt integrated holistic strategies such as One Water [16], Future World Vision [17], Net Zero Urban Water [18], and Water in a Circular Economy [19,20] to reach a long-term equilibrium between water demand and supply.

Although multiple avenues exist, the final state of water supply will be driven by local and regional conditions and the available technology, and will be subject to social acceptance. In many locations, water supplies are stressed due to a range of factors. Local circumstances will steer changes in water systems over time to meet new demand and supply conditions. What will future water supply systems look like and how will adaptations be tailored to local circumstances? This paper describes an international web-based project-focused seminar in which those questions were put to engineering students and post-doctoral teams from multiple universities. It reports on the seminar structure, team formation, conclusions reached by the individual teams; and commonalities and major differences between results for different settings, as well as benefits to the participants.

2. Motivation and Background

Communities—including those in megacities and in rural areas—are experiencing water shortages due to excessive demand and full utilization of current and, possibly, diminishing supplies. These conditions compel the water industry to innovate in ways that have not yet been accepted or even foreseen. However, it is unlikely that the historical approach of tapping a new water source or allowing unsustainable groundwater withdrawals will be acceptable. Several significant questions must be addressed, including: how will the future water distribution (WDS) and supply systems be configured and how will new data sources impact their design, control, and management in the short and long term?

The motivation for this seminar began with informal discussions with utility staff on how water supply would change in the next 20 to 50 years. Most foresaw minor differences, with more and better use of data as a recurrent theme. Planners and upper-level management would likely identify other changes, but staff visions are indicative of utilities' conservative natures.

As noted, researchers have considered the question of extending supplies and that, in some cases, significant changes to utilities' and the public's mindsets were necessary. The next step in examining the need/acceptance of change was to host a session at the 2018 joint Water Distribution Systems Analysis/Computing and Control in the Water Industry conference held at Queen's University in Kingston, Canada. The session, entitled "Envisioning the future of water distribution and supply" [21], was an audience-driven dialogue [22] on envisaging the future of water supply infrastructure and control. The conversation centered on:

1. What will the WDS/water supply infrastructure look like in 2035? In 2060?
2. How will increasing demands, decreasing supplies, societal decisions, and regulatory constraints impact the manner in which water is supplied in 2035? In 2060?
3. What WDS/water supply system data will be collected and how will it be analyzed and used for WDS management in 2035? In 2060?

The session was led by authors Kevin Lansey and Joby Boxall, and Dr. Vanessa Speight. They encouraged the audience by giving examples of potential changing conditions and gave a summary of the TWENTY65 [23] project led by the University of Sheffield.

A lively discussion ensued, which is summarized in the appendix. The comments were quite broad; understandably so with such broad questions. Expectations ranged from "same as today but older and in poorer condition" to the use of distributed water sources that are treated and closely monitored with higher-density sensing systems. Implied in the causes were a combination of acute (earthquakes, network contamination) and chronic (population growth, water availability, and climate change) events that will drive changes and adaptations, including transitioning from current "clean" sources to indirect and direct potable reuse. It was seen that these drivers would motivate the pace and magnitude of change.

The WDSA session raised a number of key issues affecting water supply but did not answer the question of how water supply might change in the future. As part of a Fulbright Fellowship application, authors Lansey and Daniela Fuchs-Hanusch conceived of a web-based, multi-university seminar to facilitate a shift from a broad perspective of water supply to examining more concrete conditions. Volunteer students from multiple countries would form teams to bring perspectives from different cultures. The teams would prognosticate future systems and compare results, as well as attempting to understand cultural impacts on decision-making. The remainder of this paper summarizes the seminar, its goals and structure, and outcomes. In addition to focusing on the driving question of water supply changes, the seminar had opportunities for participants to work in a unique environment and their conclusions changed based on interactions with colleagues from different cultures.

3. Seminar Goals

As conceived, this seminar had objectives related to water supply planning and for the participants. Regarding long-term water supply, our goals included the following:

- Bring students together with alternative skill sets and cultural perspectives;
- Examine a range of settings and identify the commonalities and differences between solutions;
- Present/develop ideas/solutions that think outside the conservative water planning mindset;

For participants, our goals included the following:

- Pose and encourage creative thinking on an open-ended problem
- Develop abilities to interact, communicate, and collaborate with a new group of colleagues;

- Understand cultural perceptions and differences;
- Contribute to building an international community of young water professionals.

Our seminar was completed as COVID-19 restrictions were put in place. A broader goal was to demonstrate that participants from a diverse range of locations could collaborate; and that a multi-university, multi-continent seminar could be successful using video conferencing tools. In some ways, this has been demonstrated by many groups over the past few years. However, at the time, the ability of this group to collaborate through brainstorming and develop professional products across cultures using these tools was novel.

4. Web-Based Seminar Structure

4.1. Participants

A group of university faculty was invited to join the seminar with their students and post-doctoral scholars participating in the project teams. Table 1 summarizes the universities and faculty involved. Of note, the time zones for the full team spanned a total of 20 h (UTC-7 to UTC+12). This, unfortunately, led to some seminar and/or team meetings taking place at difficult times for some participants. All seminars for the entire group were held using the Zoom video conferencing platform. Individual groups used other applications and video conferencing tools (see Section 5.1). Finally, of import, participation in this seminar was purely voluntary and students did not receive course credits for their contributions. The faculty greatly appreciates the students' efforts, that took time from their focused studies. The group of 24, (of whom 13 were women and 11 were men) included two post-doctoral fellows, 13 PhD students, and nine MS candidates/undergraduate seniors.

Table 1. Participating universities, faculty contacts, and associated seminar participants.

Faculty Contact	University	Country	Participants *
Joby Boxall	University of Sheffield	United Kingdom	1
Maria Cunha	University of Coimbra	Portugal	3
Daniela Fuchs-Hanusch	Graz University of Technology	Austria	3
Donghwi Jung	Korea University	Korea	1
Kevin Lansey	University of Arizona	United States	4
Avi Ostfeld	Technion—Israel Institute of Technology	Israel	1
Juan Saldarriaga	University of the Andes	Colombia	9
Kobus van Zyl	University of Auckland	New Zealand	1
	University of Cape Town	South Africa	1

* Students and post-doctoral researchers, not including faculty members.

Not all participants were working with or at their faculty contact's institution. For instance, Cunha's PhD students were not working at the University of Coimbra during the seminar. Further, Lansey was organizing and coordinating the "Future Water" web seminar from Graz, Austria. Figure 1 highlights this circumstance by depicting the number of persons involved in the web seminar; comprising faculty, post-doctoral fellows, and students, by location and institution.

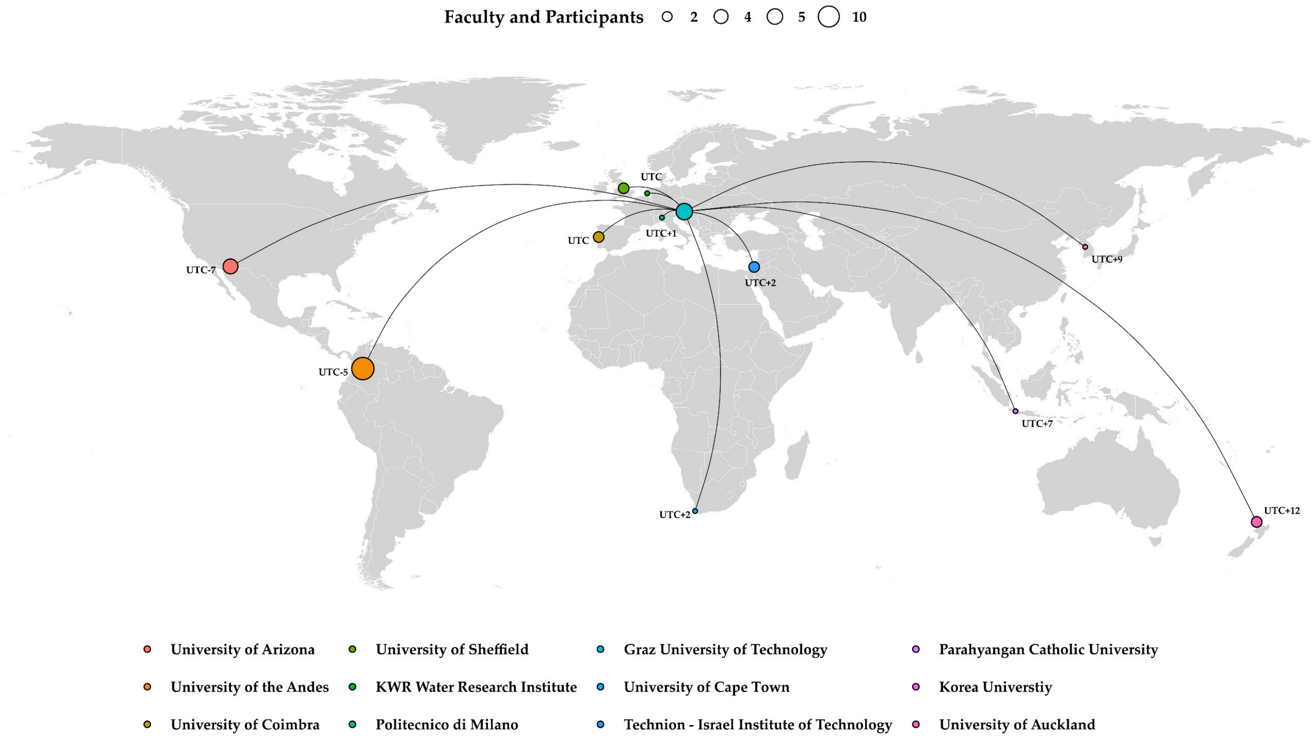

Figure 1. Faculty, research fellows, and students involved in the web seminar by institution and time zone.

4.2. Seminar Content

As summarized in Table 2, the seminar was intended to be a student-driven activity, with support from faculty and a few lectures. The seminar began with several faculty presentations by Boxall, Fuchs-Hanusch, and Lansey. These were intended to give the students a perspective on water system evolution. Boxall described TWENTY65, his project with a broad vision of water supply in 2065, including developing novel technologies to meet this goal. In a follow-up lecture, drawing on personal notes and Water 4.0 [24], Lansey summarized the evolution of water supply systems in general and gave a detailed discussion of Israel's water history. He then provided a summary of the history of water supply in Tucson, Arizona [25,26]. Fuchs-Hanusch gave an overview of the interactions between drivers, technology changes, and growth of Graz, Austria [27–29].

Table 2. Session information.

Session(s)	Topic	Speaker (s)
1	Course introduction and scope	Lansey/Fuchs-Hanusch
2	TWENTY65—Project overview	Boxall
3	History—Tucson, Israel, Graz	Lansey/Fuchs-Hanusch
4–9	Team reports	Project teams

4.3. Primary Drivers to Water Supply Innovation: Technology or Need?

Like nurture versus nature, the question of what drives changes in a water supply system can be driven by the need for water or new technologies to provide water. Historical development in Tucson and Graz (noted below), was strongly influenced by technology that improved water quality and the ability to pump and move water. New pumping technology permitted Tucson and other communities to move away from riverine water sources to access groundwater. In Tucson, this shift continued until it was recognized that groundwater levels were being significantly and unsustainably impacted and causing land subsidence. Pump technology similarly permitted Graz to grow away from its central city.

Conversely, as water shortages occurred—led by arid regions such as Arizona and Israel—water policies changed and defined the needs for new technology. Water reuse for different purposes and new supplies altered the landscape. Compared to simple disinfection of groundwater, with the introduction of Colorado river water to the region, Tucson constructed a state-of-the-art water treatment plant. In addition, the water distribution system structure was significantly altered from hub (well) and spoke subsystems to a tiered system of pressure zones that increased in elevation toward the surrounding mountain ranges. In Israel, centralized planning controlled every drop of water and encouraged the development of new technologies for water reuse, monitoring, and agricultural practices.

In the seminar's formative stages, it was envisioned as technology-centered. That is, groups would identify one or more technologies and describe their necessary extensions and adoption conditions. The techno-centric focus was highlighted in the list of technological advances that were identified as projects' foci in the invitation to faculty to join the seminar, as follows:

- Alternative and non-water-based fire suppression;
- Local/regional decentralization of water/wastewater and supply;
- Reduced-cost desalination;
- Point-of-use water or next-generation wastewater treatment;
- Net zero water goals;
- Catastrophic event planning/resilience;
- Inexpensive sensor systems;
- Water conservation;
- Water quality testing kit;
- Highly efficient variable speed pump motors;
- Water stress due to climate change/water scarcity/population growth.

As discussions evolved, including Boxall's presentation on the Sheffield TWENTY65 project—that was technology-driven but focused on settings to determine the best set of applications—the seminar focus shifted toward that structure. To that end, a collection of settings was posed. The teams' tasks were then to identify the technologies and approaches to develop an integrated, resilient, and reliable water supply system for that setting. In essence, what would the structure of the system look like to meet its needs given the constraints of the setting? Existing, anticipated, or completely novel technologies could be part of that solution. Specifically, participants were asked to consider the following aspects and research questions when developing solutions for their team's setting:

1. Given one of the settings with external forces driving change, what will a water supply and distribution system (WSDS) system look like in the year 2050 for this location?
    - Description of a physical WSDS system and major changes from today's system;
    - Discuss how the WSDS would change over time (stage-wise) to minimize risk and excess costs while satisfying present needs in a resilient manner;
    - New technology implemented or needed (gaps)—be creative and think broadly.
2. At a minimum, consider the following metrics/impacts:
    - Cost;
    - Resilience/robustness to significant events;
    - Water quality/health/risk to contamination;
    - Sustainability.
3. Provide alternatives and justification for the following options.
4. Specifically, identify sensing technology and data availability that would be useful for this location and how the data would be used.

5. Setting characteristics.

- Location;
- Supply;
- Density—growth location and rate;
- Centralized/decentralized treatment;
- Expected climate change impact;
- Supply system age.

Beyond the listed basic instructions, seminar participants received a list of settings, containing a detailed description, as well as information on its historic evolution, expected future developments, and underlying drivers. These descriptions were provided to support participants in selecting and ranking their preferred settings; and to serve as initial catalysts for communication within the teams. Specified characteristics included current and future demographics, population density, a general location, and anticipated future climate.

For example, setting six was described as a "smaller, older retirement community with little expectation for growth. Demand is already overtaxing current supplies. Rainfall and supply (groundwater recharge and direct withdrawals) will be reduced due to climate change". As for the other settings, a list of details, drivers and expected developments was provided for setting six, which was not assigned to a project team (see Section 4.4), as follows:

- Semi-rural community, much of the infrastructure development and construction occurred in the 1960s;
- Inadequate and poor-quality surface supply and ongoing groundwater mining that must be stopped;
- 100,000 people—slow growth rate (1%); mainly with retirees;
- Population density—1200 people/square mile, single-family homes and low-rise (three-floor) apartment buildings;
- Climate will be drier and warmer with less local rainfall (from about 1 m today to 700 mm by 2050);
- Rainfall occurs relatively uniformly during the year.

Beyond facilitating setting selection and team formation, the descriptions and lists of drivers served as the basis for discussions within the teams and with their faculty supervisors; thereby playing a vital role in the development of solutions, as outlined in the following sections.

4.4. Team Formation Seminar Timeline

With the focus on place and future as primary characteristics causing communities to adapt, the set of six settings were defined (Table 3). Participants ranked their top three of the six settings. Based on the rankings, a set of problems to be solved was used, to distribute participants to five teams. A constraint was added that no two students from the same university/advisor could work together, except for those from the University of the Andes, who were limited to a maximum of two students per team. All participants except one were given their first or second preference, with the vast majority assigned their first preference. Table 3 provides an overview of the selectable settings. As a result of the selection process and the number of web course participants, setting six was not assigned to a project team.

Table 3. List of settings and assigned groups and project teams.

Setting	Description
1	Megacity renovation
2	Low-water-available community
3	Medium-density, large city

4	Rural community
5	Coastal tourist city
6	Small city, contracting population with a drier/warmer future *

* Not assigned to a project team.

The seminar organizational meeting and faculty presentations were held in December 2019 and early January of 2020. Team assignments took place after the New Year. The first team moved very quickly and presented their work on 30 January. Two teams presented in the first half of February and the last pair presented by the end of the month (Figure 2). Presentations were made to last one hour, including questions. Slides from each team's presentation and the video recordings of all sessions (except for Boxall's video) are available upon reasonable request (see data availability statement).

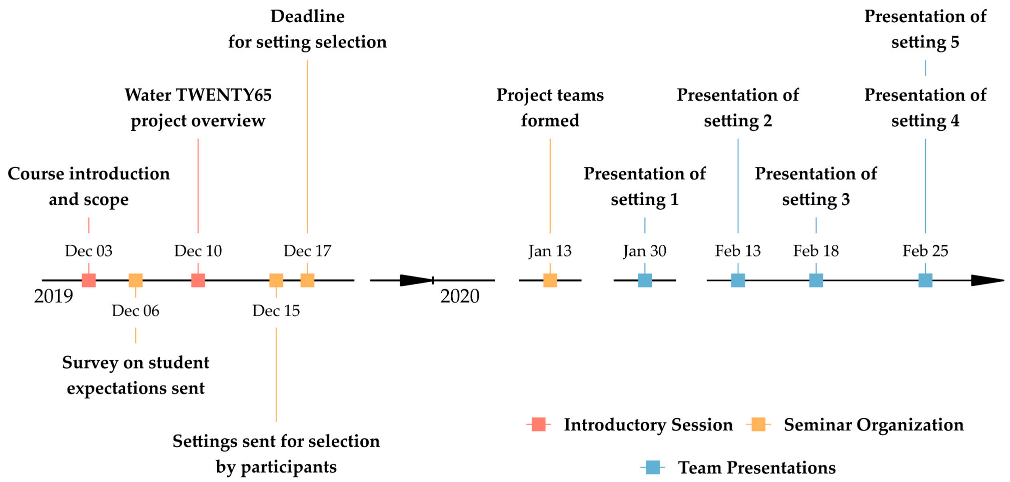

Figure 2. Timeline of the web seminar, taking place between the fall of 2019 and the final presentation in February 2020.

5. Future Water Systems—Team Presentations

5.1. Setting 1—Megacity Renovation

The first of the five project teams, supervised by Donghwi Jung of Korea University, comprised a master's student, Vadim Naranjo; two PhD students, Flavia Fuso and Camilo Salcedo; and a post-doctoral fellow, Younghwan Choi. All were working in different time zones between Bogotá (UTC-5), Tucson (UTC-7), and Seoul (UTC+9).

Team 1 examined the renovation of a megacity. The setting was a large, highly populated region, undergoing conversion to a denser population. In the course of this development, the region was to transition from older construction to new, larger, and taller buildings. Additional expansion was to be assumed to occur on the outer rings of the city, but that growth was limited by topography and the ocean. The new development would increase demand, but pipe replacement was to be considered expensive due to the high traffic on most streets. The following details, drivers, and expected developments were provided to the seminar participants:

- Part of megacity on Asian coast;
- Surface supply from upstream reservoirs;
- Limited groundwater storage;
- High-density (15,000 people/square mile), large population (6 million people);
- Expansion in the central city at 4%/a –pockets of infill vacant areas and replacement of low buildings with high-rise apartments, a few new high-rise developments on outskirts;

- Minor use of reclaimed water;
- Centralized water and wastewater;
- Climate change impact—higher temperatures, higher annual precipitation; largely from more torrential events.

Megacities are characterized by having a population exceeding 10 million people, and rapid growth in recent decades. Beyond its size, the city plays a key role in providing educational, cultural, and recreational activities to the region; as well as concentrating the workforce and economic activities. Further, megacities are focal points of the development of countries [30]. Based on the latter definition, cities such as Seoul, London, Shanghai, Mexico City, and Bogotá are considered megacities now, or will be by 2050 (Figure 3).

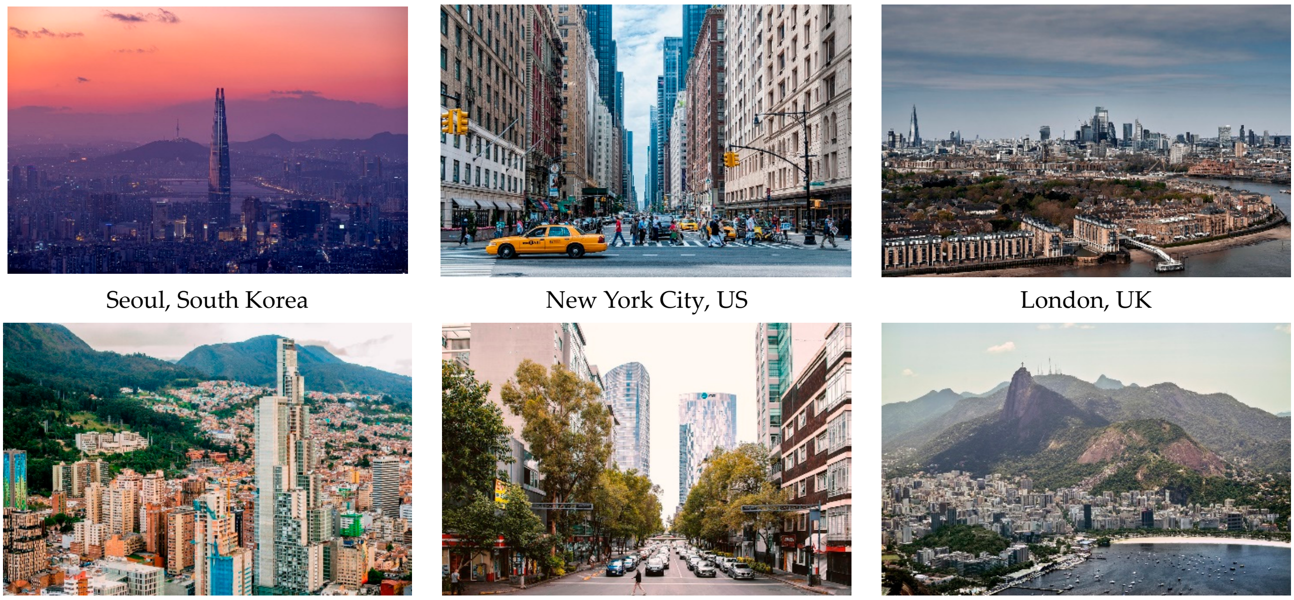

Figure 3. Cities that will be considered megacities by 2050, according to [30].

In addition to the drivers described above, megacities face similar consequences due to their size. For example, water distribution network topologies are generally gridded in alignment with their streets, that increases residence times and potentially water stagnation [31]. Unplanned development and continuous migration from smaller cities [32] may cause unpredicted water demand increases, resulting in significant pressure deficits; particularly when new, multi-storied buildings replace historic homes. Regarding water availability, climate change will impact megacities in different ways. For example, droughts are expected to be more frequent in Seoul, while precipitation will likely intensify in Bogotá.

Ultimately, the impacts of climate change will increase the vulnerability of the supply networks. Due to the hyperconnectivity among systems and infrastructures within megacities, cascading failures are a significant risk. These potential outages will severely affect the population by simultaneously degrading not only the power grid, but also water and transportation networks as well [33]. Further, as more cities rely on technology-based solutions such as information and communication technology [34] and smart devices (e.g., smart meters or real-time control systems) to control and optimize their infrastructure, the risk of cyber-attacks grows.

To envision the future of WSDS, a change of design paradigms must be acknowledged. In the 1960s and 1970s the goal was to provide water to meet consumer demand. Over time, engineers were motivated to provide safe water. In the early 2000s, the focus transitioned to providing reliable and healthy water supplies, and WSDS development has since been shifting towards a bottom-up approach in public service and policy. As such, Team 1 proposed a solution comprising four objectives: (1) system renovations and preparedness for changing environments; (2) integrated managing maps; (3) smart grid network; and (4) improved cyber security.

To address system renovations and preparedness for changing environments, solution 1 was divided into two components: pipe renovations and net zero water impact. Given the extent of megacities, asset renovations must be done without interfering with other infrastructures (e.g., transportation). For this purpose, trenchless rehabilitation methods were proposed for water infrastructures, as they ensure minimal impact on the day-to-day operation of megacities, given their fast installation and extensive applicability to water supply and sewer systems [35]. The risks and higher costs associated with this technology can be mitigated with real-time monitoring that identifies and prioritizes replacements before pipe failures are required, and monitors the effects after construction.

To prepare for changing environments, net zero water provides a framework for facing water quantity problems at the source rather than the distribution system. If the source of a megacity is at risk, a strategy combining a conventional WSDS and reclaimed water offers a more sustainable supply in the long term. However, the use of reclaimed water requires new design, monitoring, and operating methodologies.

To address the second objective, integrated management of megacities using interactive mapping was proposed. This map combines the infrastructure of a city (e.g., water supply, wastewater and drainage, power or transportation), to exploit the expertise of stakeholders to identify potential failure; reduce the risk of cascade failures; and initiate prompt, coordinated responses. This solution, however, requires coordination across administrative agencies and utilities.

Objective 3 can be addressed by building a smart grid to improve WSDS operation and reliability. Four key elements in the development of a smart grid are: (1) online monitoring through sensors and meters; (2) data transmission to a central location; (3) technologies to process the recorded data; and (4) analysis of this data for decision-making processes. Given the size of a megacity, its WSDS would likely be divided into manageable blocks to facilitate monitoring and control; such as district-metered areas (DMAs) or pressure management zones. Block size depends on the priorities of decision-makers and site-specific conditions. Smaller zones improve demand and pressure management and anomaly detection, while fewer larger blocks reduce monitoring efforts and may be more cost-effective. The combination of mapping and smart grid is intended to reduce water losses through early break detection and pressure/leak management to support sustainability goals. The fourth objective pursues high cyber security through the development of relevant software systems and security measures. Smart networks are prone to cyber-attacks that affect infrastructure controls including water/wastewater treatment plants. Given the accelerating use of cyber–physical systems in megacities, use of tools such as epanetCPA [36] to identify the threats to and vulnerabilities of critical infrastructures is an urgent need. Deep-learning concepts have been applied to pinpoint WSDS components under attack with data commonly collected by water utilities [37]. Finally, the involvement of the public in the information loop was recognized as a key component for smart (mega)cities. Under the umbrella of "citizen science", residents can provide useful information on social media and other data-collection platforms. Such a citizen science strategy was used to perform a sampling campaign in Flint, Michigan, to expose a Legionnaires disease outbreak by generating insights beyond the capacity of the utility [38].

5.2. Setting 2—Low-Water-Availability Community

The second project team consisted of a master's student from Bogotá, M. Luisa Colmenares; and four PhD students, Adriana Arcelay and Monica Pickenpaugh in Tucson, Georg Arbesser-Rastburg in Graz, and Flavia Frederick in Bandung. They collaborated with Professor Maria Cunha of the University of Coimbra on the low-water-availabilty community setting. Their setting was an established city that is located in a low-water-resources area, that is expecting a growth in the population and reduced water supply due to climate change. Rainfall was concentrated seasonally with long periods of little rainfall. Details on the conditions and drivers for this setting were proposed as follows:

- External surface supply;
- Limited amounts of groundwater can be withdrawn to maintain aquifer balance and avoid mining;
- Groundwater storage possible;
- Distribution system expanding since 1940;
- 1 million people, mid-density (3,000 people/square mile);
- Expansion of outer regions with a moderate pace (2%/a.);
- Minor use of reclaimed water;
- Centralized water and wastewater;
- Climate change impact—higher temperatures, reduced annual precipitation but more intense storms.

The eponymous water scarcity was identified as the key constraint for setting 2. Reduced surface water and groundwater resources, combined with changing weather patterns and the ongoing suburban expansion of the city, amplifies the critical role of resource availability over time. The city of Tucson, Arizona (Figure 4)—a metropolitan area in a desert setting—which, like the generic setting, is characterized by urban growth and water scarcity, was selected to convey the developed water management solutions.

Figure 4. The city of Tucson, Arizona served as an example of low-water-availability communities.

Reclaimed water use beyond a small number of private properties, parks, and schools was promoted to manage supply issues. Concerns about water quality (e.g., due to pharmaceuticals and other contaminants) were addressed [39] using specific examples from Israel and Singapore [40]. For wastewater treatment and urban drainage, sanitary and stormwater sewers were separate systems to support water reuse, to deflect stress from the central wastewater treatment plant and—with impending more frequent high-intensity rainfall events—to reduce urban flooding.

Aligning with the city of Tucson and water management in the state of Arizona [41,42], storing water in above-ground basins and to recharge aquifers [43]—and expanding the use of large-scale desalination plants [44] in coastal areas (e.g., the Gulf of California [45])—were recognized as options. Technological caveats of desalination (such as biofilter-fouling) and production cost and transport in open channels or pipelines were assessed. Limiting groundwater extractions to reduce the stress on overtaxed aquifers was also encouraged.

Agriculture was identified as a main water consumer in Arizona. Consequently, shifting from inefficient irrigation practices such as flood irrigation was envisioned as a significant step in preserving water supplies. Beyond reducing water use in the primary sector, a water market [46] was recommended as a means to (re)allocate water spatially and temporally. Water trading was seen as an effective course of action to enable water storage and use of fresh water for higher-value uses in the secondary or tertiary sector.

Beyond the lack of a water price that reflects the actual cost of water, suitable legislation, and community buy-in were seen as important factors in battling water scarcity. Policy changes and awareness campaigns involving a wide range of stakeholders (i.e., policy makers, the scientific community, and the public) were presented as key elements for implementing measures to minimize water use. Specifically, information and support for consumers to install low-flow fixtures and to understand socially responsible, dynamic water pricing (e.g., seasonal, or time-of-day tariffs) were considered substantive steps toward ensuring sustainable water use in communities with limited water availability.

5.3. Setting 3—Medium-Density, Large City

Three master's students from the University of Cape Town and the University of the Andes—Melissa De Sousa Alves, Sara Criollo and Cristian Gomez—worked on setting 4 with Anika Stelzl, a PhD candidate at Graz University of Technology; and João Marques, a post-doctoral researcher at the University of Coimbra. Kevin Lansey of the University of Arizona served as faculty facilitator. Although the participants of Team 3 were working from three different continents, the total time difference was "only" 7 hours.

According to the setting description, a large city below megacity scale, was to be planned to avoid overpopulating. Bogotá (Figure 5) and similar cities were identified as representative of this setting. The location of this new development was a low-productivity agricultural region outside of a river floodplain, requiring a diversion channel through the city. A single city center, high building, and population densities were planned. The nearby river served as the primary water source, providing an average daily supply of 35 L per capita at full buildout, but the supply had significant inter-annual variability. Detailed constraints and drivers for this setting, as outlined in the problem statement, are as follows:

- Part of megacity in an earthquake prone region (several hundred kilometers from the coast);
- Surface supply;
- Limited groundwater storage, partly due to contamination;
- High density (15,000 people/square mile) expected population of 2 million;
- Planned community with dense central city;
- Climate change impact—higher temperatures, lower annual precipitation in the water source, and higher temperatures.

Working from the above-mentioned description, Team 3 conceived a new sustainable eco-city in a greenfield site with well defined boundaries to prevent over-population. The idealization of critical water systems to keep the city functional relies on the use of proper decision methods, taking into account that these infrastructures may have to deal with earthquakes, and limited availability of surface water and groundwater.

Figure 5. Aerial view of the city of Bogotá; a medium-density, large city on the verge of becoming a megacity.

Sustainable city planning entails resilient, robust, adaptable, and flexible water systems that are designed, monitored, and maintained by using powerful optimization methods.

These tools will be able to handle multiple objectives, multiple plausible future scenarios and phased interventions. The solutions that can be obtained for the water systems—defined based on objectives related with economic, social, technical and environmental measures—are of great interest. Furthermore, due to the high uncertainty related to climate change, seismic activity, and water demand increase, several plausible future scenarios should be defined. The optimization methods to plan interventions to be implemented in a phased scheme should be adapted as new information becomes available [47].

Team 3 proposed a sponge city and urban planning to improve the city's ecological environment by replacing impermeable areas with green spaces through green building roofs, permeable pavements, rain gardens and wetlands to increase rainwater infiltration and reduce surface runoff and rainwater evaporation. This concept will contribute to solving water scarcity problems by increasing aquifer recharge, while promoting environmental protection by reducing surface water contamination.

Separate urban drainage systems for wastewater and storm water were recommended to reduce the wastewater sewer's capacity and increase velocities for low flows. To reduce energy consumption, wastewater treatment plants would capture biogases produced during treatment and use that product to generate the plant's electricity.

In the city center new, large buildings were conceived to reduce water consumption using rainwater harvesting systems designed to store water from wet seasons for later use. In single-family homes away from the city center, rainwater harvesting was recommended. To avoid problems related to mosquito breeding and extensive use of storage space, it was implemented locally in neighborhoods and communities. As this city is located in a low annual precipitation zone, rainwater harvesting is insufficient to solve the water scarcity problem. Therefore, when constructing new buildings, water reuse would be mandatory. Greywater recovered from washbasins and showers is stored, and treated to be used in toilets, washing machines and possible outdoor irrigation. Rainwater harvesting and water reuse will reduce the potable water consumption from the public WDS and wastewater volumes requiring centralized treatment.

WDS will be monitored by strategically placed sensors and connected by an extensive and robust communication network. Water quality, pressure, flow, and seismic activity data are collected in the field and stored in a data center. Data reports would expose trends and real-time parameters for alarm triggering to proactively respond to network events such as pipe failures.

Smart governance initiatives would be implemented for operating of distributed water infrastructures. These could include training the community with awareness campaigns on water conservation; guidelines for installing alternative water systems; safe use of greywater; application of International Organization for Standardization (ISO) standards; definition of data strategies and legislative requirements to be promulgated. These initiatives will make water system infrastructures safer and more secure, improve sustainability and reduce operating costs.

5.4. Setting 4—Rural Community

Team 4 adapted the existing water infrastructure of a declining, rural community—that was primarily built in the late 1800s—under the guidance of Daniela Fuchs-Hanusch at Graz University of Technology. Team members Laura Enriquez and Kevin Garcia, master's students from the University of the Andes; PhD students Mohamad Zeidan from the Technion—Israel Institute of Technology; Ina Vertommen, affiliated with the University of Coimbra and KWR Water Research Institute; and Frances Pick, a post-doctoral research associate at the University of Sheffield, coordinated their efforts across six time zones.

Setting 4 had seen only limited infrastructure improvements over the past 50 years. Surface supply was extracted from the river and a shallow aquifer supply, using bank filtration. In some parts of the community, groundwater was contaminated by pollution from now-closed factories. The provided changes, details, and main drivers for the setting are as follows:

- Small decreasing population (13,000 people decreasing by 1%/a), migration of the young away from town to nearby cities;
- Central supply;
- Aging existing distribution system from 1880; high leakage losses and oversized pipes;
- Adequate water surface supply drawn from river and shallow bank groundwater withdrawals;
- Sporadic poor water quality events due to changes in river quality;
- Limited revenue.

At first, declining communities seemed to be a foreign concept to the team, before realizing that familiar regions [48] and therefore local water utilities were already up against the challenges imposed by the setting description.

To gain a better understanding of the specific issues that utilities in rural areas with depopulation are facing, Team 4 contacted a Dutch utility. Among the main issues identified during this exchange were the difficulty of relating population decline (Figure 6) to reduced water demand, given a trend towards smaller households with a higher per capita demand. Climate change, combined with sociodemographic shifts, are reflected in changing demand patterns and increased peak demands that can be heavily influenced by a few, large customers (e.g., farms or dairies).

Figure 6. In some rural regions of the Netherlands, the population is projected to fall by 16% by 2040 [48].

In terms of infrastructure, aging and oversized systems lead to: (1) water losses and, in turn, increased contamination risk; and (2) long residence times and low flow velocities in pipes that can impact water quality. A declining population, if leading to a decrease in demand for water, further exacerbates the lower velocities in pipes and longer residence times. Considering aspects of policy, awareness, economics, environmental concerns, and technologic innovation, Team 4 developed four possible solutions to future-proof the water infrastructure to overcome the population shrinking beyond 2050 and aging infrastructures.

The first solution, "do nothing", maintains the status quo by turning water infrastructures into a patchwork and only implementing ad hoc repairs. This solution, however, reduces trust in the utility. With reduced revenues, repairs and investments decrease, while pipe failures increase, and water quality problems become more likely.

In contrast to this reactive approach, the second solution focuses on "structured design" [49]; a proactive planning approach tailored to facilitating a gradual transition from existing aging, oversized networks to redesigned WDS's. The renovated pipes will be replaced as or before they fail. WDS pipes will be identified in three subgroups ordered by purpose, pipe size, and number of loops, as follows: (1) primary transport mains, (2) secondary distribution networks with some service connections, and (3) tertiary distribution networks that supply most customers and will be converted to branches.

Combined with targeted maintenance and rehabilitation, structured design mitigates issues such as water quality risks, induced by common normative design criteria (e.g., fire flow requirements). An integrated design concept allows legislators and utilities to consider the implications of new (building) codes when adapting a WDS, while focusing on reliable water supply as the main purpose of their systems.

A third alternative—decentralized, "off-grid" concepts—has been applied for rural regions with dispersed populations that are not amenable to structured, centralized water infrastructures due to their costly upkeep and preventative maintenance. In these locations, decentralized water supply and treatment systems can be implemented for individual houses or facilities, as well as small-scale systems for clusters of customers. Water, sourced from groundwater wells and surface water bodies; or derived from sustainable rainwater or greywater harvesting is stored in tanks and treated at the point-of-use, or at the point-of-entry of households, contingent on the intended use [50].

Rainwater use for irrigation and certain appliances, combined with greywater use for irrigation, can reduce water consumption considerably. In rural areas with declining populations—where agriculture or livestock farming drive water demand—combinations of centralized supply and treatment for households, and decentralized systems for non-potable uses represent a highly adaptive option [50].

While off-grid systems can be deployed faster than centralized systems, operation and proper function are difficult to monitor and maintain. They therefore require education and awareness to ensure technical proficiency and high customer self-reliance. In addition, decentralized systems can be costly and/or unable to satisfy peak demands.

The fourth solution outlines the use of "collapsible and flexible pipes", for rural WDS with high diurnal or seasonal demand fluctuations. These fluctuations require larger storage facilities and result in significant variations in velocities, which can have adverse effects on water quality and the lifespan of pipes. During low-demand periods, the current aging system will experience an increase in pressure, potentially leading to leakage. Water stagnation can result in sediment accumulation and promote biofilm growth, resulting in deteriorated water quality. To address these fluctuation-related challenges, Team 4 took inspiration from the cardiovascular system and studies on the shape and flow-section-adaptive properties of blood vessels [51–53]. When transferred to a WDS, flexible pipes mimicking these properties can change their shape based on flow and pressure, allowing for larger or smaller flow sections during periods of high or low demand, respectively. Despite the significant promise of adaptive pipes, advancements in material science (e.g., shapeshifting spacer or electroactive polymers) are needed to develop durable yet flexible materials for practical application.

5.5. Setting 5—Coastal Tourist City

The fifth and final team, supervised by Kevin Lansey of the University of Arizona, comprised two master's students—Maria Gonzalez and Andres Ariza—working from Bogotá; and three PhD students—Laura Lunita Lopez, Sanghoon Jun, and Michael Pointl—participating in the web course from Auckland, Tucson, and Graz, respectively. At 20 h, this team had to bridge the biggest time difference in the seminar.

Team 5 focused on a coastal resort town characterized by substantial tourist influx between May and October. The setting is dominated by seasonal variability and continued rapid expansion, making adaptation and optimization of existing water infrastructures challenging. Growth in the hospitality industry is driving new construction near the coastline, leading to further semi-annual shifts in water demand. In contrast, water use is constant year-round in the less dense hinterland, where the majority of permanent residents live. While tourism accounts for the majority of the city's tax revenue, it causes existing supply systems to operate at capacity near the shoreline and places the city's main water source at risk of saltwater intrusion. Consequently, the project team had to focus its efforts on developing resilient solutions for the diverging seasonal, geographic, and economic constraints within the setting [54,55]; as detailed in the following list:

- Stable year-round population of 4,000 people that is gradually increasing (0.5%/a);
- Summer population increases dramatically due to large tourist influx of visitors from May to September;
- Peak summer population reaches 36,000 on summer weekends compared to fewer than 200 in winter;
- Summer influx is expected to increase by 50% by 2050;
- Transmission system from 1950, distribution network added with new development with pipes relatively uniformly distributed between 1960 and 2010. Installed pipe materials were typical of time of installation;
- Piping system in main hotel/shoreline area is becoming undersized with new hotel/restaurant demands;

- Groundwater supply from inland wells, concerns with salt intrusion if increasing well pumping;
- Treated wastewater is sent to the ocean via pipeline away from shore;
- Existing housing is not dense except near beaches (1,500 people/square mile);
- Climate change has a small effect on rainfall and temperature patterns;
- Substantial tax base from tourism.

Given the complex constraints of this setting, Team 5 focused on implementing policies and legislation, relying on community involvement and new business models (e.g., public–private partnerships). The goal being an accelerated roll-out of innovative technologies and new management strategies focusing on modular water infrastructures to mitigate the city's financial risk (i.e., if tax revenue from expected tourism growth did not materialize). With new policies and an adapted regulatory framework, it was possible to go beyond maintaining and optimizing the existing supply systems with conventional measures such as implementing DMAs and introducing decentralized measures at appropriate site-specific scales. The community shown in Figure 7 is indicative of the many coastal cities with densely built-up shorelines and less consolidated hinterlands that would benefit from tailored modular solutions.

Figure 7. Gold Coast, Australia; a city showing the decrease in building density from the shore, which is characteristic for setting 5.

Implementing modular supply systems builds upon the notion of facilitating controlled transitions. In the face of extreme seasonal changes in water demand, adding components to existing, centralized water distribution, drainage, and treatment systems requires significant planning from multiple entities [56]. To optimize existing infrastructures, Team 5 relied on the implementation of open DMAs for pressure and water loss management [57]; an asset management strategy considering the effects of the coastal location (e.g., sand in the water distribution system and pipe corrosion [58]) and the implementation of an advanced metering infrastructure for machine learning-supported online monitoring and control. Making use of digitalization was considered a key element in combining existing and new measures, not only ensuring a safe and secure water supply, but also guaranteeing a seamless transition between operation at maximum capacity during summer months and low off-season demands.

Decentralized measures to systematically store and harvest rain- and greywater [59,60] were added to the existing networks on the shoreline and in the hinterland but differed in size and number. Larger tanks to store and treat water were placed in the center of tourist activity, and designed to be appealing to tourists, either on a building scale (i.e., water tanks as aquariums in hotel lobbies, vertical greening systems) or at a neighborhood level (e.g., urban wetlands serving as recreation areas [61]). Smaller, decentralized systems in the hinterland were intended to guarantee a reliable, low-cost water supply at the individual residence level (e.g., rainwater tanks and solar-powered treatment with on-site reuse) to support ground water resource conservation.

The transition to an adaptive, modular WSDS, combining available and new technologies, requires specialized experts and technicians transforming the water utility to a high-tech service provider and generating new, year-round employment opportunities. As an example of an innovative solution to produce fresh water that can only be implemented by utilities within a feasible regulatory framework and qualified personnel, a futuristic, energy-self-sufficient, floating saltwater treatment plant was proposed [62]. Tailored to the setting, such a system could serve as tourist attraction at the end of a pier and simultaneously reduce the risk of saltwater intrusion [63,64] into groundwater resources during the taxing summer months. Given its mobility, it could be leased to other coastal communities during other times of the year to provide water for recharge at those sites.

6. Discussion

6.1. Group Dynamics and Communication

Group interactions and the seminar structure are discussed first, as these appear to influence the resulting water system configurations. An expected factor of conducting an international seminar—particularly one spanning the globe, as for this group—is time. As is often the case with students' variable schedules, finding meeting times was not a simple process. Given the time zone coverage, in many cases, some group members had to sacrifice sleep to participate in a single video conference call. The second time element was participants allocating time for this volunteer activity. Participation was based on interest in the topic and advisor encouragement. As noted, no student received academic credit for their efforts beyond authorship on this article. It was encouraging that all of the faculty initially invited to participate agreed to join this effort.

Following the introductory sessions and setting assignments, the teams organized themselves beginning with initial contact via e-mail from the faculty supervisor. After an online kickoff meeting, communication between video calls shifted to messenger apps, such as Skype or WhatsApp, facilitating direct, simultaneous communication between all group members, no matter the time of day. Online meetings took place between classes and after working hours. Consequently, most were scheduled via e-mail and calendar apps, ensuring automatic adjustment to local time zones. Sharing of materials and real-time collaboration in documents and presentations relied on cloud solutions, such as Google Drive.

Once the teams began to meet, cultural and seniority/experience differences in their communication and problem-solving approaches were evident in some groups. As noted, one seminar goal was to bring together students from different cultures with the hope of establishing long-term relationships. However, no inter-cultural content was provided to prepare students for these interactions.

Differences in communication and interaction styles rooted in the participants' respective cultural backgrounds became obvious in the course of the groups' collaborations. In this context, the three behavioral categories outlined by Lewis [65] for cross-cultural communication were reflected in general discourse, organizational, and technical aspects. Talkative members (e.g., those from a multi-active background such as South America or the Middle East) could dominate discussions, providing much context and many examples compared to individuals from reactive regions (e.g., Asian countries). Linear-active team members from the United States, the Netherlands or Austria, were prone to task-oriented, direct communication and meeting organization.

In hindsight, giving participants some perspective on cultural differences either through readings or in a seminar session could have better prepared the teams. A session that began with literature on expected differences, followed by discussions of their appropriateness to the participants may have been helpful for teams to understand how others and they themselves, are perceived in the team. It could also encourage team members to think about how to modify their interactions to convey their arguments most effectively.

In addition to introducing students to the dimensions of working in a multi-cultural environment, highlighting the different levels of proficiency in the seminar's lingua franca, English, would have eased communication early on. Only a minority of the involved faculty and students were native speakers. As a result, some written and spoken exchanges while organizing and conducting group meetings got lost in translation; in particular, when proficient speakers relied heavily on idioms or (pop) culture references.

In contrast, this difference in communication styles was less of an issue during seminars and team presentations, where verbal points were underscored by slides with images or figures.

Seminar participants ranged from undergraduate seniors to post-doctoral scholars. Some had concurrent or previous industry experience. While the teams demonstrated respect for all, both experience and seniority played a role in communication and team leadership, as well as in the development of solutions. One or more persons were implicitly chosen as group leaders once the teams started to organize themselves. This perceived hierarchy shaped the dynamics of all groups, albeit to varying degrees. Nonetheless, group leadership—which often coincided with seniority—shaped the interactions, as well as the developed technical and organizational solutions.

6.2. Solution Development and Presentation

While group solutions often had significant similarities, later teams distinguished themselves in other ways. The first team presentation was only about 3 weeks after the faculty talks (see Figure 2). The last two were 8 weeks later. The initial talk provided a presentation format and structure, including providing context of communities in similar settings, that was generally followed by most teams. This group also focused on seeing a future to achieve the desired goals using existing approaches. As the talks progressed and teams learned from earlier presentations, risk taking, and novel ideas increased. In addition, several teams looked more holistically at their setting. For instance, the latter groups included more comprehensive monitoring systems. Teams began to be more creative in both their presentation style (e.g., using comic book characters to illustrate the challenges of their setting) and in solving challenges faced in their setting (e.g., variable diameter pipes that maintain velocity and water quality). Although time and commitment did not permit re-design of their systems, an iterative design process or starting with this seminar's presentation for new approaches would be a valuable learning experience in a more formal course setting.

7. Conclusions

An international webinar was conducted via video conferencing, and brought together faculty, researchers, and students from universities in nine countries. The webinar's early sessions covered historical perspectives of water system development and visioning for future water system structures. In the remaining sessions, participant teams laid out their visions for the water supply system based on defined settings. All sessions were held via teleconference over a three-month period.

Interestingly, even under widely different settings of water availability, community size and climate change predictions solutions were more similar than different, with reuse for some purposes and rainwater harvesting recommended for many settings. Solutions generally maintained centralized facilities, with the exception of rainwater. Recognition and the ability to monitor systems was highlighted by several teams. Fit-for-purpose and highly decentralized supplies were not emphasized.

Team dynamics, interactions and visions were influenced by cultural differences, experience/academic level, and perceptions of acceptable water use. Risk-taking in solutions was encouraged and increased as team presentations progressed. The lack of social science/governance specialists and their input to the recommended system structure and its governance was recognized by the all-engineering specialist teams. This gap should be rectified if future webinars are organized. In addition, more detailed information on costs including energy and requirements for resilience and, more explicitly, sustainability criteria would enhance the setting descriptions. Further, existing systems and transitions to a future system were not a major focus, but this is a significant issue in practice and could modify recommendations.

Future similar seminars are encouraged to enhance communication and build relationships and research collaborations among early-career water planners. Further, findings of these efforts would not only be invaluable for the conceptualization and scheduling of such seminars, but also for the design and optimization of future water systems across the globe.

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