MEDRC

TRANSBOUNDARY WATERS

PRACTITIONER BRIEFING SERIES

Issue 9

Transboundary Water Technology: Applied Technology in Transboundary Waters

Transboundary Water Technology:

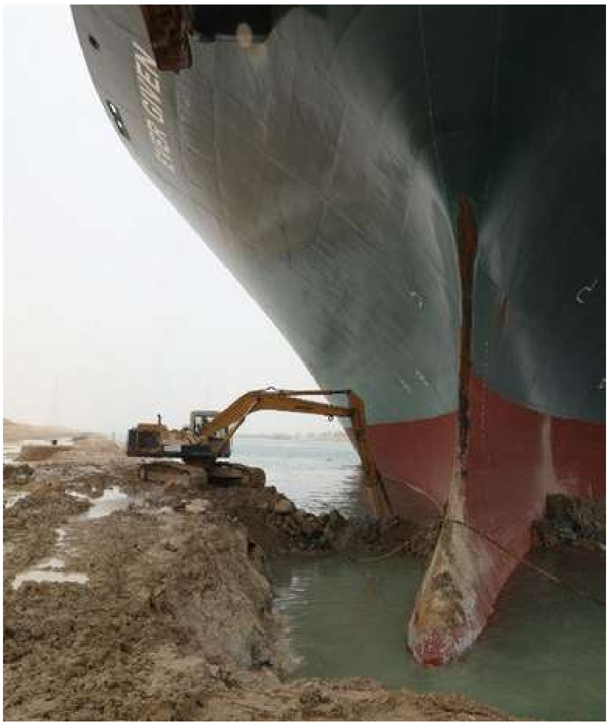
Applied Technology in Transboundary Water

Shared Innovation:
Technology can help to solve transboundary environmental problems and increase the efficiency of natural resource use. However, innovative tools must be matched with political will.

Introduction

Technology is helping to revolutionize the 21st century, from advances in materials sciences to telecommunications, making the world smaller, smarter, and more efficient. Some critical examples include battery innovations for higher density and capacity, 3D printing technology, gene editing techniques and mRNA technology underpinning rapidly developed Covid-19 vaccines, the development of artificial organs, or multi-use rockets making access to space more accessible. [1]

While the progress on some fronts has been swift and even continues to gain steam, other areas have been more gradual or are simply limited by their physical realities. As a familiar example, while electricity generation can be dispersed and is relatively cheaply transferred through powerlines, water cannot be due to its physical characteristics, and must typically be sourced locally.



Efforts to excavate the Ever Given, run aground in Suez Canal (2021)

International shipping is an industry that has vastly gained in importance over the past century with the rise in globalization yet is still limited by the speed of ever larger tanker ships, the realities of navigating the uncertainties of the high seas, varied port bureaucracies, or the pitfalls of running aground in a major global shipping choke point. Notably, the solution to freeing such a massive container ship from the Suez Canal was still a remarkably low-tech one. While the ability to see how actually clogged up the international shipping lanes were, was very much high-tech and viewed from space. While technology can help us to see and analyze the severity of the situation, the actual solution to the problem was still old-fashioned 'grunt work'. There are similar competing dynamics in new technologies and their application to transboundary waters.

A first question to ask may be, what makes a technology transboundary? Something that is applied across state borders or watershed boundaries, or something that is shared between two states, or a technology which is applied globally. For this briefing we will consider all of the above. The technological advancements of new desalination membranes or processes that can be deployed across the globe. The measurement of watersheds and other global data gathered from space. As well as the monitoring and utilization of such data that is shared between states.

For transboundary water, technological advancements can be a boon to enhanced cooperation through the improved gathering of more accurate data and information, more precise resource management and efficient operations, which are

Practical Summary

- Transboundary water technologies are those tools and materials that facilitate the development, preservation, and sharing of natural water resources, including technology that is shared across borders or applied across borders.
- Transboundary technologies can provide new tools and methods to deal with complex environmental problems, particularly by collecting and sharing information or data.
- Enhanced data collection and application can better inform the decisions of policy makers, improve the precision of international agreements and their efficacy, and more efficiently employ scarce water resources.
- Across sectors, technology has advanced at different speeds, often based on national priorities or physical limitations, which are inherent to the water sector. Refinements and enhancements of well-established technologies or methods are often more expedient than new technology.
- Technology adoption is affected by a range of factors from economics to politics, as well as efficiency and industry inertia.
- Technologies are ultimately tools that can only succeed as far as they are applied and utilized effectively, or that political will allow.
- Support for innovation is critical long-term, while reduction and mitigation are readily available.

so desperately needed for the sustainable use of shared water resources. The key components of water management are the design of the infrastructure, systems planning that is integrated, and real-time monitoring and control of operations. Technological advancements can continue to improve upon each of these fronts.

Transboundary Water Technology

Desalination Processes | Membranes | Remote Sensing | GIS Platforms | Harmful Algae Blooms | Materials Science | Renewable Energy | Biofuels | IWRM | Blockchain

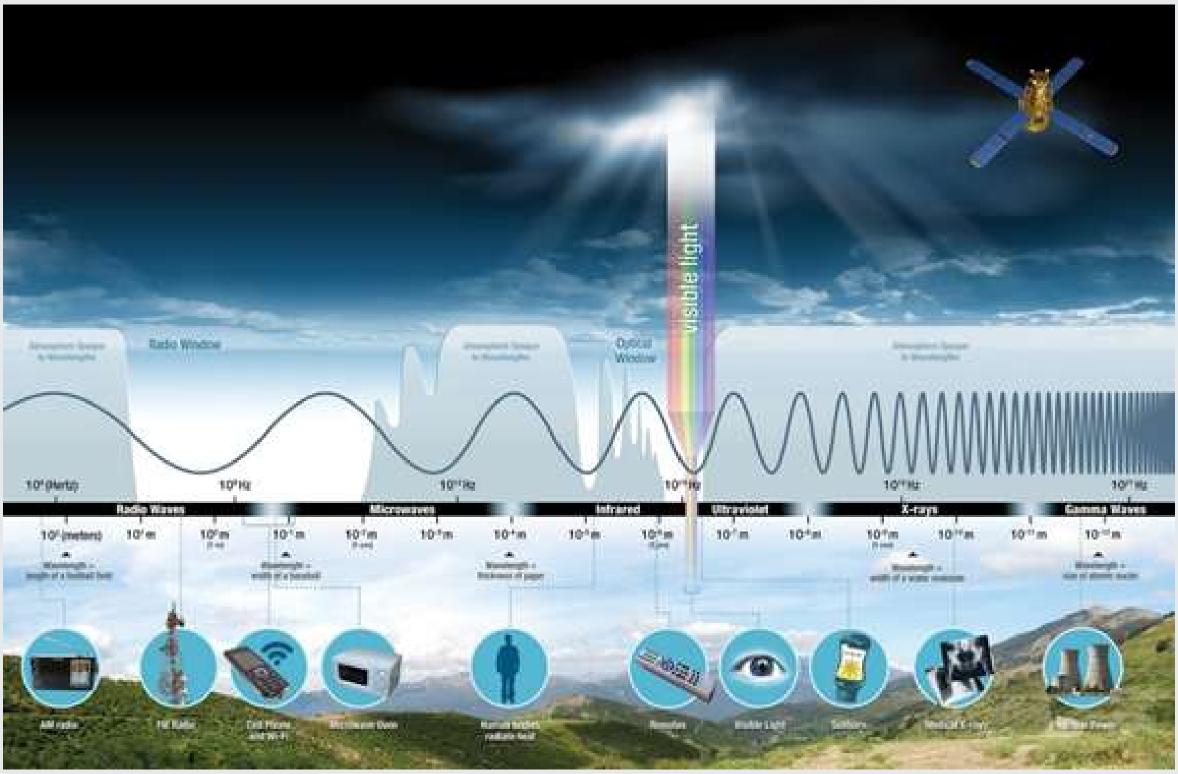
Water treatment and desalination plants can operate more efficiently to better use currently available water resources. New water resources can be developed to meet increasing demand. And with more accurate data and information that better accounts for the complex relationships and system feedback, transboundary cooperation and agreements can be better tailored to the realities and needs of competing groups in order to make them more effective.

Data is critical to sound decision making; to understanding the resources available, how they interact with their surrounding environment, and importantly how they may change over the coming decades and centuries. It is an unfortunate reality that the focus of global responses to climate change are now shifting from climate change mitigation towards climate adaptation, with profound impacts for the planet. However, it is critical that states are not complacent in the assumption that they will innovate away their problems.

Technology is ultimately a tool that can only be effective as those who wield it, and forms only one component of a cooperative solution. Alongside these tools is the need for political will to want to cooperate across boundaries and develop cooperative agreements grounded in international law. Technology's role should be to help bolster those agreements by making them better informed and more adaptive, while opening up new possibilities to increase limited resources.

Remote Sensing - Get the Data

Advances in technology have helped to provide more accurate information and data, as well as better control and management of natural resources through enhanced data collection techniques and systems, so that resources can be more efficiently deployed or reused, or even simply accounted for.



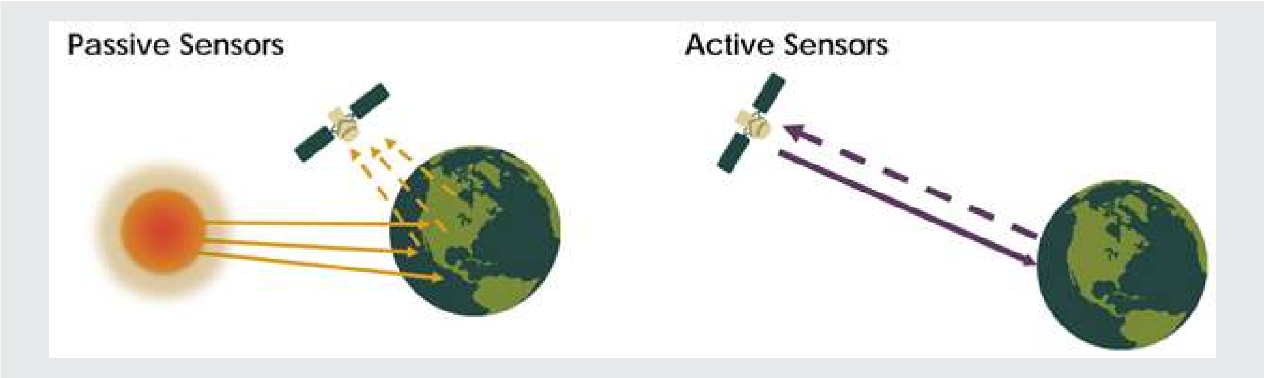
Source: science.nasa.gov

One of the most important of these tools has been Remote Sensing, which allows for the gathering of immense amounts of data from a great distance, and which would otherwise be a highly labor-intensive and time-consuming process, if not outright impossible.

On a basic level, the definition of Remote Sensing is the gathering of information from a distance without any direct contact, which could technically be a short distance, or very far away. As such, basic cameras, and medical imaging such as MRIs, X-rays, or sonographs are a type of remote sensing—gathering information without any physical contact. Typically, however, the field is considered in its most remote form, with the use of satellites orbiting the earth and their advanced instruments on board. While any camera is therefore a remote sensor, another critical component is light, or more specifically the electromagnetic spectrum and energy radiation.

In the modern sense of remote sensing, it is the gathering of information from a distance (remotely), using sophisticated sensors, typically deployed on a satellite or UAV/aircraft to detect and record energy (radiation), which is either emitted or reflected by the Earth. These systems can also allow us to see beyond our rather narrow visible light to view across the electromagnetic spectrum, to gain deeper insights on Earth's resources. By viewing from space, remote sensing allows for the gathering of data from the hardest to reach areas, including the polar regions of the Earth. Based upon their set orbits, data can be collected in a time series over long periods of time to gain further insights into the same geographic location or object. This gathering of information over time can also reveal patterns and changes, key to understanding watersheds, water quality and supplies, water's interaction with vegetation, the ocean's turbidity, or even for predicting hurricanes.

The process of detecting and monitoring emitted radiation allows analysts to make inferences on the physical characteristics of our Earth, primarily through the use of algorithms, based on the known physical relationships between the light spectrum and the objects being observed. This is done with both Active and Passive sensors that work in opposing ways. Active sensors provide their own energy source directed at a target, and then detects and measures the reflected or backscattered radiation from the target being investigated. While passive sensors detect the natural radiation of the object, most typically that of sunlight. In a simple sense, a camera with a flash (active), or a camera picking up the ambient light (passive). There is a wide array of the types of sensors



Source: NASA Applied Remote Sensing Training Program

with some overlapping qualities, which can be deployed on either satellites or aircraft like UAVs, and vary greatly in their distance or remoteness.

For satellite remote sensing like the NASA Landsat Missions (e.g. Landsat 7 & 8, and the soon to be launched Landsat 9), they collect data from an orbit around the earth. Their orbits are sun-synchronous near-polar orbits about 705km above the Earth, completing an orbit of the Earth every 99 minutes. This is considered a Low-Earth orbit (LEO), which is a distance between 160km and 2,000km above the Earth. Other satellites such as those used for GPS are in Medium-Earth orbit (MEO), or more than 20,000km above the Earth. By contrast, commercial airlines fly at about 10km above the Earth, or 32,000 feet.

An orbit is reached by a satellite through achieving a high enough horizontal velocity with a sufficient altitude to escape the drag of the Earth's atmosphere. This drag is what constitutes a Low-Earth Orbit, and is normally under 1,000km above the Earth, but can be as low as 160km. Even satellites that are in orbit are actually still falling, but can adjust their position periodically to maintain their orbit. The mean orbital velocity that is needed to maintain a stable LEO is about 7.8 km/second, or 28,000 km/hour (17,000 mph), but this minimum speed reduces with an increased orbital altitude. This is why rockets do not truly fire straight up, but pitch over to obtain a sufficient horizontal velocity to enter an orbit. [2]

Remote sensing satellites reside in either polar or non-polar orbits, typically in Low-Earth orbits, or are geostationary (GEO). Geostationary satellites orbit at around 36,000km above the Earth, moving in sync with the earth's rotation and thereby allowing them to always view the same area of the Earth. This is critical for communication satellites as their relatively fixed position above the earth allows antennas placed back on Earth to be pointed directly at them, without needing to continuously rotate or re-establish connections. Polar orbits generally move over the Earth's North and South poles within about 20-30 degrees of pitch, as opposed to moving along its equator, and are also a type of LEO.

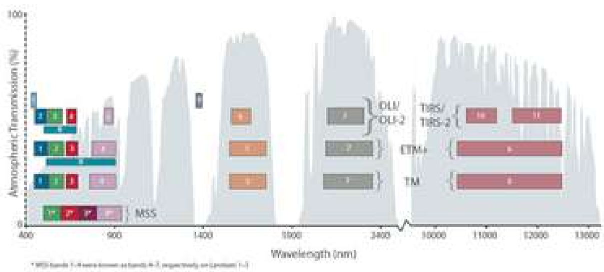
Sun-synchronous orbits (SSO) are a specific type of polar orbit that is matched to the rotation of the sun, such that they view the same spot at the same time of day each day. This important for measuring changes over time, which includes looking at intervals of days, weeks, months or year, and can reveal patterns related to sea-level rise, water quality changes, deforestation, flooding or fires. These occur at about 600-800 km above the earth, moving at 7.5km/second. MEOs are basically any distance between a LEO and a GEO. [3]

For some perspective of the Landsat missions' orbits and position, the International Space Station, which can be seen orbiting the Earth and watched via live stream online any time of day, sits at about 400 KM above the Earth and completes an orbit in roughly 93 minutes. [4]

Onboard the ISS, a number of instruments are also equipped performing a variety of missions, including DESIS—DLR Earth-Sensing Imaging Spectrometer, ECOSTRESS—ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station, and GEDI—Global Ecosystem Dynamics Investigation. ECOSTRESS uses thermal infrared (TIR) measurements over the diurnal cycle (24-hour pattern) to address critical questions on plant-water dynamics and future ecosystem changes. While GEDI characterizes the effects of a changing climate and land use on ecosystem structure and dynamics to improve quantification and understanding of the Earth's carbon cycle and biodiversity.

Source: Spotthestation.nasa.gov

Once a remote sensing device such as a satellite is set in its final orbit, it can then make observations using its on-board instruments. As mentioned, for the NASA/USGS Landsat missions, these include Enhanced Thematic Mapper Plus (ETM+), thermal IR (infrared) sensors (TIRS), Operational Land Imager (OLI). These systems use multiple spectral bands that allow it collect data and to see the earth in various forms of visible light and infrared, including near-infrared, short-wave infrared, thermal, and mid-infrared. The updated Landsat 9 mission will continue this ongoing record of Earth observation, with enhanced systems such as OLI-2 and TIRS-2, that will duplicate and enhance the prior missions. The below chart shows these instruments relative to their wavelengths:



Source: usgs.org

With all the technology and effort to place active and passive measurement devices high above the earth we receive a great deal of benefits, from the GPS functionality on our phones, to an enhanced view of the changes in our climate and seeing where those emissions are coming from. Tools and platforms are able to take this high-tech photography data and wield them to inform policy.

Below is a comparison of the same spot on the earth from 1990 to 2019, showing the changes in the coastline caused by sea level rise in Jakarta, Indonesia. In addition, NASA has been able to take more accurate global measurements of evapotranspiration, measurements that were previously elusive, showing an even greater increase in the speed of the Earth's water cycle. This increase in the speed of evapotranspiration has huge implications for vegetation and the rate of drying on land, impacting crop yields, causing draughts, and changing weather patterns. This can in turn lead to more stress upon surface and groundwaters that are relied on for human societies.

Landsat image of sea level rise in Jakarta, Indonesia. Source: earthobservatory.nasa.gov

Color-infrared photography (CIR) or false-color photography renders scenes in colors not normally seen by the human eye, and without the interference of atmospheric haze. Red tones indicate vegetation, with lighter tones and pinks showing waning. Soil is shown in white, blue, or green with darker tones showing greater moisture in the soil. Water is shades of blue, with shallow areas reflecting the material beneath, from sediment to sand. Using both visible light and infrared light, the earth can be shown with both the visible and invisible wavelengths to convey more information, and confirm or track changes in chlorophyll, water quality, vegetation, sea-level rise, or saltwater intrusion.

Example Landsat 8 image of water & sediment. Source: geoimage.com.au

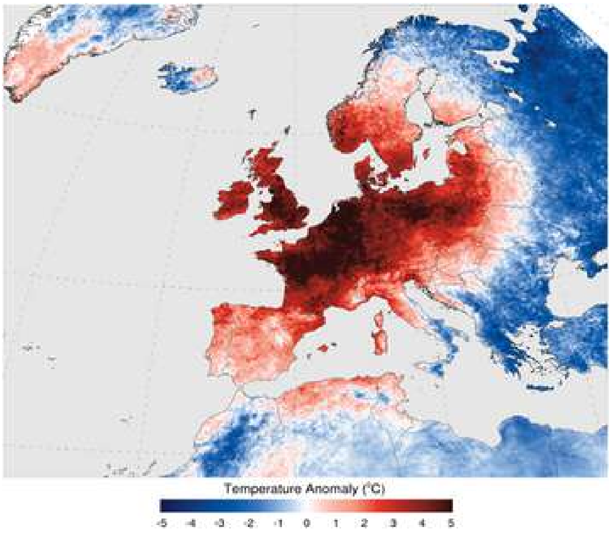
Turning Remotely Sensed Data into Images & Maps

Technology can help us to better see, understand, and measure a problem to gain valuable insights. Getting the data is the first step, the next question is how to utilize this data in order to identify patterns, show change, and inform policy. The power of GIS platforms is to layer remotely sensed data and present it in a way that is easier to understand and interpret intuitively.

To utilize the data gathered via remote sensing, it needs to put into a format that is useful in order to inform decisions and best illuminate patterns. Going beyond raw data numbers or time series graphs, the use of layered maps and images can help to illustrate the earth in unique ways and help to provide verification of a shared data set that can inform policy decisions, or international water agreements.

Data points and figures like a '2-degree Celsius change in the earth's temperature on average' can have an abstract feeling to people in terms of what they mean to our daily lives. Seeing it illuminated as GIS platforms layering data over geographic maps can visualize the data in a way that makes it more tangible or real. These tools are key to illuminating the risks of climate change to various industries and roles, from executives to politicians.

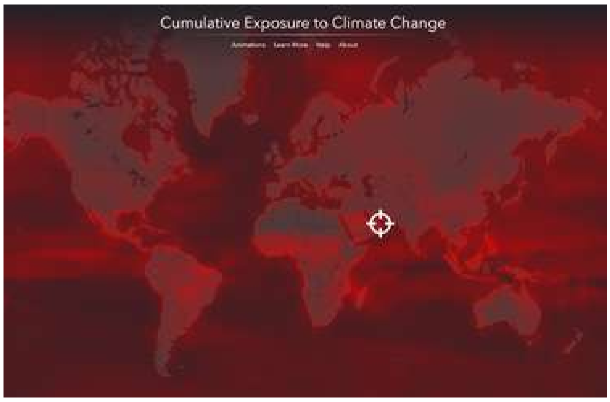
From temperature changes to droughts, fire, water scarcity, sea level rise, or changes in ocean chemistry, the use of location intelligence alongside data points allows for the interactive visualization of how climate change will impact humanity. These tools also allow



Source: climate.nasa.gov

for modeling scenarios based on these data inputs and measurements plus various assumptions, to see how different policy choices will impact our future.

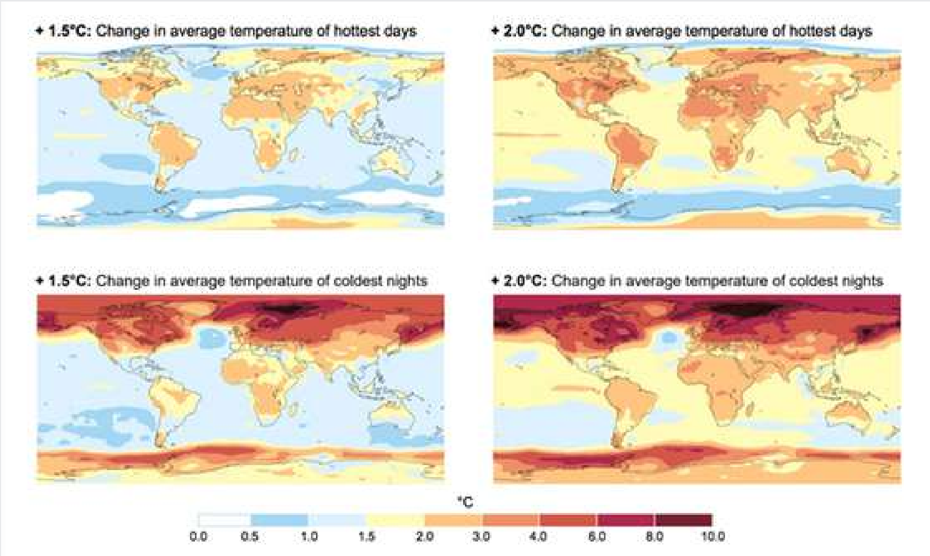
Another example below shows the "Business as Usual" scenario, which can then be easily compared against strong or moderate mitigation efforts within a GIS platform. ESRI and the Mora Lab have developed the interactive Cumulative Change index, which models this. [5]



"Business as Usual", 2060, Cumulative Change Index, Mora Labs Source: youtube.com

Data is only useful if it is acted upon and shared. This is true for water resource data between transboundary countries, and it is true for climate modeling, which remains the ultimate transboundary collective action problem. GIS platforms that allow the interactive visualization of data can help to inform decisions and raise awareness about what these changing data points mean in practical terms.

NASA ARSET—Applied Remote Sensing Education and Training provides resources for water practitioners to



Source: climate.nasa.gov

learn about how to use remote sensing, work with the data, and apply it practically. [6]

Water Practitioner Resources
https://appliedsciences.nasa.gov/what-we-do/water-resources/practitioner-resources

ArcGIS: Platforms & Sharing Data

Data collection is the start of the process. Confirming it and utilizing it is the next step, which is where ArcGIS platforms can help to leverage this technology in practical and useful ways.

A GIS—Geographic Information System—is a technological tool used to display layers of data onto geographical maps, including remotely sensed data, as well as any other recorded data inputs. They can be used by a variety of people from urban planners to geologists or hydrologists, environmental scientists and academics, and by both individuals or research institutions and governments, to manage information and data across a variety of areas, to inform their decisions. This can relate to agriculture, water management, forestry policy, crime statistics, political districts, or even emergency vehicle routes.

One example is Carbon Mapper, a non-profit organization that collects and monitors CO2 and Methane emissions via remote sensing, producing maps and time series that can independently verify carbon emission reductions, and has helped to catch gas leaks from pipelines or powerplants. These efforts help to clearly show the otherwise invisible damage that is being done by many industries and can also be a key source of verification for climate agreements to monitor and confirm reductions in GHGs.[7]

Carbon Mapper – "Public Good Non-Profit to Accelerate Climate Action"
https://carbonmapper.org/

The variety of applications possible is indicative of the power of this tool to leverage the data that is collected, to analyze it, and present it in a way that yields greater insights. Often deployed through web interfaces or purpose-built programs, this tool brings together remote sensing data with other data series, layering geographic information to make spatial patterns and relationships clear. Most recently this has also been deployed in the tracking and management of the Covid-19 pandemic, tracking the spread of cases, hot spots, aided contact tracing, as well as monitoring vaccination rollouts and uptake. [8]

In a practical way, these tools can help to assess the spread of a pandemic, determine the most efficient allocation of resources to the hardest hit areas, and deploy emergency treatment centers where they are needed most. ArcGIS platforms were able to be quickly deployed and scaled to analyze and address the pandemic, but still rely on their underlying data collection efforts in order to output analysis. [9][10]

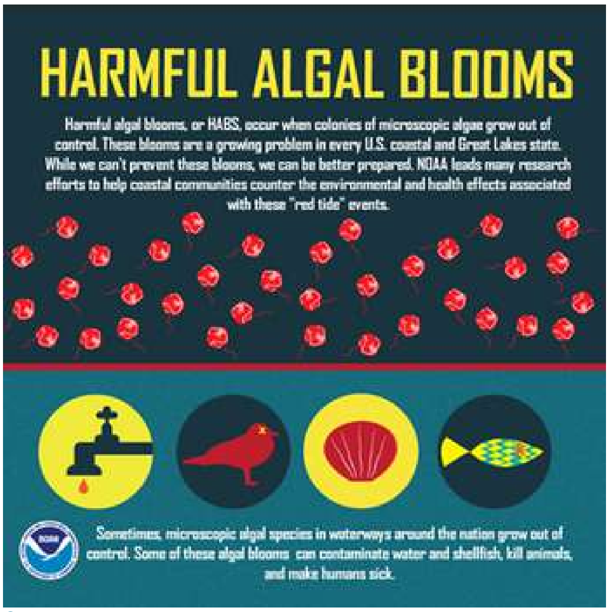
Although less pressing in nature, the same tools can be effectively applied, scaled, and shared for transboundary water issues. A core problem for cooperation between riparian partners is the assessment and tracking of water resource availability, its allocation and usage, with clearly agreed standards and tools. ArcGIS platforms and hubs can help to alleviate this through shared remotely sensed data, layering this data to geographic areas, allowing for better management and tracking of shared resources. With the ability to independently verify measurements, and then secure this information ledger through other tools like Blockchain distributed databases, technology can help to establish and enhance trust for sharing information that is seen as critical to national security.

While it has always been possible to measure water data, standardizing, sharing, and updating this information has proved challenging politically, particularly under conditions of scarcity and conflict. Technology can help to ease some of these burdens, but political will must allow for them to be implemented. Some successful examples of this already exist and can be useful for lessons in applying these tools to ongoing conflicts, such as with the GERD and disagreements on the rate of filling, and its downstream impacts, or the mechanism to monitor and adjust this process. Transboundary water agreements that build in the use of technological tools for greater objectivity and verification can help to build and better inform cooperation mechanisms that uphold the international watercourses principles of No Significant Harm and Equitable Use. [11]

The Big Data Analytics and Transboundary Water Collaboration for Southern Africa, or the 'Collaboration' at it is known, aims to improve water security by promoting "big data" approaches to enhance regional collaboration between states. Partners in the Collaboration include; the South African Department of Science and Innovation; the Water Research Commission of South Africa; the SADC Groundwater Management Institute; the USAID Southern African Regional Mission; the U.S. Geological Survey; and the USAID Center for Water Security, Sanitation, and Hygiene.

Another example is the Integrated Ocean Observing System (IOOS) that is looking to directly monitor and share data about our oceans and tracks a very particular problem of HABs.

HABs: Harmful Algae Blooms & Technology



Source: noaa.gov

Harmful Algae Blooms or HABs occur when a colony of algae grows very rapidly and causes damage to the ecosystem around it, including wildlife and humans. This can cause a range of damage to water supplies, disrupt desalination plants, destroy fish stocks, and can even kill people. Not all algae are toxic however, and not all algae blooms are harmful. Yet a growing number of such events appear to be HABs, according to experts. [12][13]

As global average temperatures increase and oceans warm, so do the conditions that create more and more HABs. This has led to water shortages in places like Michigan, as residents could not drink from their local water supply. With an increasing reliance on desalination technology on shorelines around the world, the increase in algae blooms are a critical and growing challenge that must be addressed. Prediction tools and remotely sensed data can help to track and respond to such events in order to minimize their impact [14] [15]. At root, however, is an increase in their causes, from phosphorus and nitrates caused by farming to higher CO_2 levels alongside warming oceans.

Algae on its own is neither good nor bad—they are a group of plant organisms founds in water, which consume CO2 and serve as natural part of the ecosystem's balance [16]. As phytoplankton they serve as a key food source for fish and other aquatic life that supports the overall marine ecosystem. They are also one of the largest Carbon Sinks, by consuming CO2 from the atmosphere. However, other forms, such a cyanobacteria (blue-green algae), produce toxins that cause real harm to both fish and humans. Cyanotoxins can cause both short and long-term health effects, from nausea and vomiting to cancer and liver failure. [17]

Source: noaa.gov

'Red Tides' are another form of HABs caused by toxic algae Karenia brevis that turns waters red in hue, while poisoning fish, triggering asthmas in humans, and making shellfish toxic to eat. This occurs annually in Florida and produces and a strong neurotoxin. However, the algae in a bloom need not be toxic in order to cause damage or kill marine life. A large algae bloom that then dies and decays can deplete the available oxygen in the water, thereby causing death to marine life in the area. This has been seen in areas with farming activity near rivers and lakes, as the runoff of nitrates and phosphorus feeds larger algae blooms, and the confined body of water is depleted of its oxygen.

While remote sensing and shared data platforms can help to identify or warn of HABs, more investment is required to have an expanded Integrated Ocean Observing System (IOOS) that is deployed around the globe. [18]

HABs represent another example of the negative externalities of climate change caused by human activity. While the algae and the blooms are naturally occurring, human activity has a direct impact on increasing their size and frequency, by feeding it more nutrients and warming conditions that promote their growth.

Meanwhile, algae technology offers many new opportunities to create next-generation biofuels and carbon sinks that can actually power our future, while reducing this CO2 cycle that creates HABs.

Addressing Climate Change and carbon emission remains the key issue that must be globally addressed, and our methods for providing freshwater is part of that picture. "In 2019, global CO2 emissions from fossil fuels amounted to 33 gigatons, with 41% coming from the power generation sector, and the remainder from the transportation and industrial sectors." Desalination technology that relies on fossil fuels is another a driver to this problem and needs to become more efficient and run-on renewable energy. [19]

Remote Sensing of Algae Blooms in the US and China. Source: ewg.org

Source: static.ewg.org

Desalination Technology: Membranes & Energy Efficiency

The most prominent source of non-conventional water around the globe today, and the technology that underpins it, is desalination. More specifically, RO—Reverse Osmosis—desalination. The processes of desalination and reverse osmosis have existed for centuries, but the technological advancements enabling the mass production of large quantities of potable water which can sustain cities, has only come into play for the last half-century. Further advancements have been made each decade since as the process is made more efficient and cost-effective, scaling up its operations, increasing salt rejection, and lowering required pressures thereby increasing energy efficiency, leading to a reliance on the technology growing in many parts of the world.

Reverse osmosis desalination plant in Barcelona, Spain.
Source: Wiki Commons

The primary methods of desalination come from distillation or thermal techniques, or membrane processes. Distillation methods include, multi-stage flash distillation (MSF), multiple-effect distillation (MED), and vapor-compression (VC), changes the waters state. Membrane processes include reverse osmosis (RO), membrane distillation (MD), nanofiltration (NF), or forward osmosis (FO), passing through materials. New processes are also being developed and scaled, such as Pressure Retarded Osmosis (PRO), Closed Circuit Reverse Osmosis (CCRO or CCD), Centrifugal Reverse Osmosis (CRO)—which are mostly innovations on the very same centuries old RO process.

MSF Desalination Plant at Jebel Ali G Station (Dubai) 1994
Source: Wiki Commons

At scale, some of the largest desalination plants first developed were MSF plants that were viable in regions with very low freshwater availability along with a cheap energy source, such as Saudi Arabia. This thermal distillation desalination process has been widely deployed in the Gulf region, turning saline water into steam in multiple stages. These energy intensive processes have typically been fed via cheap and subsidized fossil fuels, which are in abundance, in trade for more freshwater, which is scarce.

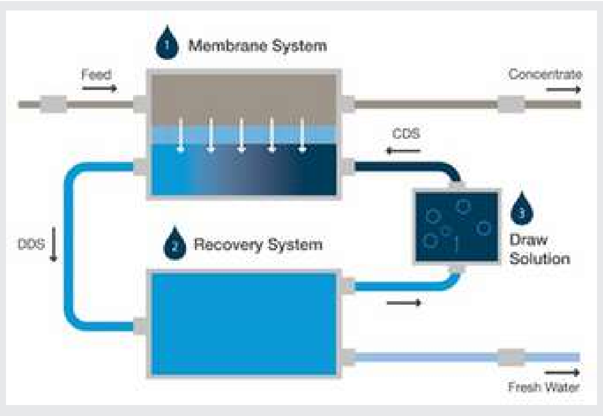
The first RO membrane desalination was done in 1959, using polymeric cellulose films or cellulose acetate (CA) to produce fresh water from saline water. Since then, the general process has remained the same, forcing salty water through membranes with great pressure, reversing the natural osmotic process. Decades on, efficiencies have been gained to yield more water and lower the required pressures and power to reduce costs or looking towards more green and renewable energy sources for the process. The driving force behind process innovations has been to reduce the costs of producing and supplying desalinated water, which is often priced below the cost to make it.

In practice, the largest contributions to the costs of this process are often related to membrane fouling, requiring cleaning and eventual replacement, plus the energy costs due to the high pressures required, and the environmental impact of the concentrated brine that is produced alongside fresh water.

Innovations in RO desalination focuses on how to deal with each of these 3 key components; membranes, energy demand, and byproducts. A key component, however, is also the carbon footprint of the plant's operation, and how clean or renewable that energy input is.

Innovations such as graphene membranes, carbon nanotubes, CCRO—closed circuit reverse osmosis technology, or more efficient electrical grids can all contribute to lowering the cost and carbon impact of producing potable water from sea water. This is critical for governments and companies as the true cost of producing fresh water is greatly affected by the lifetime operation of the plant, while tariffs are typically set well in advance, with financing costs or risk premiums established based on these numbers.

Below are some of the 'new' technologies in the areas of desalination that look to address these concerns.



Oasys Water FO System Map. Source: oasyswater.com

Forward Osmosis (FO)

Forward Osmosis is another osmotic process like RO, which uses natural osmotic pressure to pass water through a semi-permeable membrane, resulting in a draw water or clean water flow, and a concentrated water flow or wastewater. The process has so far been mostly appropriate for specific uses in plants or industries with more challenging feed water needs, and applications looking to increase overall water reuse in industrial settings.

The process can help to both treat wastewater and provide clean draw water, which can then be cycled back into a plant's operations to increase reuse while lowering pre-treatment needs or can be used for drinking water as often used in Hydration bags. For example, a FO system placed onto an industrial wastewater treatment process can help to both reduce the work of the wastewater treatment primary and secondary processes, thereby lowering its operation costs, and increase a plant's water reuse by cycling the draw water back into the plant's water supply. Systems can also be designed flexibly based on the particular needs of the plant and the water quality required. A primary advantage of an FO process is its lower power requirements and fouling issues on the membranes, increasing their lifespan. [20][21]

In Oman, the FO company Modern Water has deployed a FO desalination plant in a containerized solution. To make the draw water from the FO process potable, a second process is needed. This can be done in a number of ways, including membrane separation, but the likelihood of fouling is greatly reduced by using the FO process first. Using FO as a pre-treatment method can also enhance other forms of larger scale desalination, such as MSF or RO plants. The process has also been utilized in industrial applications in plants in power and manufacturing plants in China, using the ammonia-carbon dioxide (NH_3/CO_2) forward osmosis process invented at Yale University by Rob McGinnis, commercialized as Oasys Water.

The driving force of innovation in non-conventional water resource development is to lower costs and environmental impacts, from brine solutions to lower energy costs, or lower maintenance demands from membrane fouling. However, FO has not supplanted RO as the go-to water resource at scale.

Pressure Retarded Osmosis (PRO)

In the past decade the process of taking saline water to produce both energy and fresh water have increased in popularity, thanks to processes such as Pressure Retarded Osmosis (PRO) and Reverse Electro Dialysis (RED). The concept was first theorized in the 1950s, using osmotic pressure differences between fresh and saline water, a natural process seen when a river meets the sea and nature's quest for balance. Dr. Sidney Loeb developed PRO in the 1970s as a means to harness this process between the Jordan River and the Dead Sea, one of the saltiest bodies of water on earth. Membranes between the two water types create pressure to drive a turbine, generating electricity. However, the membranes were then too costly and difficult to make, losing out to cheaper forms of energy via fossil fuels.

Advancements in the design of membranes and 'nanotechnology', including those membranes in typical RO desalination, have drawn renewed interest in this field to develop more commercially viable systems that can generate power while reducing the fouling or blocking of membranes. Further improvements using Reverse Electrodialysis (RED, or EDR) have also helped bring this technology further into commercial viability, linking up segments to create a flow of current, sending positive ions through one side, and negative ions through the other. More unique examples of applications include using SWRO brine, the very high saline byproduct of seawater desalination, along with even wastewater, increasing the pressure differences and thus its efficiency. This provides an option for reducing the electricity requirements of RO desalination plants that produce water, lowering their carbon impact as well from less reliance on energy grids that may run on fossil fuels. [22] [23]

Membrane Distillation (MD)

Membrane distillation is a combination of both membrane-based technology, and thermal distillation technology such as MSF. With pressure differences, vapor will move through a hydrophobic membrane naturally, as a thermally driven separation process driven by a phase change. Effectively, it is a method to make better use of both heat processes and membranes to achieve thermal membrane separation, that takes advantage of a hydrophobic membrane and pressure differences in temperatures changes. Liquid water is repelled while vapor is allowed to pass through.

A number of large-scale desalination plants and trails are looking to MD as viable option for the production of water resources. However, this technique, like other membrane processes, has a variety of iterations that would qualify as MD processes, including; Direct Contact MD (DCMD), Air Gap MD (AGMD), Vacuum MD (VMD), Sweeping Gas MD (SWGMD), Vacuum multi-effect membrane distillation (V-MEMD), or Permeate Gap MD (PGMD). These applications can often be designed to order for customer needs and handle a variety of processes from seawater desalination to brine treatment, process water treatment, or removal or concentration of ammonium.

A further benefit of MD is that it is readily paired with solar energy solutions in a compact design, to have small or medium sized output plants that run on renewable energy, due to its ability to run on alternating energy without high base load requirements. This is particularly promising for arid regions with a lack of infrastructure, where a renewable energy-based technology can be deployed to create drinking water from brackish or seawater. The MEDIRAS project, Membrane Distillation in Remote Areas, is an example of this. [24] [25]

Electrodialysis (ED)

Power requirements remain the main drawback to desalinating water, whether through MSF or RO membrane processes. The electrodialysis (ED) process is less power intensive than traditional RO system requiring high pressure pumps. Salt ions are transported through an ion-exchange membrane via an electrical current in an electrodialysis cell, removing salt from the feed water separating into dilute and concentrate. A similar drawback to RO, is the need for pre-treatment and the eventual fouling of the ion membranes, decreasing its efficiency. [26]

Electrodialysis Reversal (EDR) is a type of membrane process with alternative positive and negative charged electrodes, anion and cation membranes, and a push-pull process to pass positive or negatively charged ions across the membranes, resulting in high water recovery with treatment, while also reversing this charge occasionally, to help then remove blockage and increase the length of the membranes life.

The water treatment processes of Electrodialysis Reversal (EDR) adds onto the ED process by reversing the polarity of the electrodes to change the flow of ions, resulting in better membrane longevity. This innovation has benefits of simpler pretreatment, reducing the operational cost of systems and allowing them to work in a wider range of TDS or temperatures, making them more flexible with higher yields.

Such EDR systems are being used for wastewater tertiary treatment for irrigation in San Diego, California, or to manage high nitrate levels feedwater wells in Gandia, Spain. This provides an alternative to using RO systems where either pretreatment costs or brine disposal may be prohibitively high. [27]

Continuous Electronic Deionization (CEDI)

Electro-Deionization (EDI) is the process of using electrical current to deionize water, meaning remove dissolved ions from water, or impurities. This is done without the use of chemicals and is typically a polishing treatment after an RO process to achieve very high purity levels in water, with very low conductivity. Again, this method was first used in the 1950s, and relies on using membranes and electricity to purify water through an ion-exchange. [28]

The difference between electrodialysis (ED, EDR) and electro-deionization (CEDI) is the use of resin. Both use electricity and ion-exchange membranes to remove dissolved substances from water, but the addition of ion resin allows for CEDI to be used for applications requiring very high purity levels, such as that of semiconductor industry. The electrical potential difference principle is the same in both processes, but the resin promotes the ions transport, allowing for even lower levels of connectivity (purity) of the water. Furthermore, the process continuously regenerates the resin so that it does not become exhausted or lead to downtime. From laboratories to pharmaceuticals to power applications, CEDI provides highly pure water for a variety of industries. [29][30]

Ultrafiltration (UF)

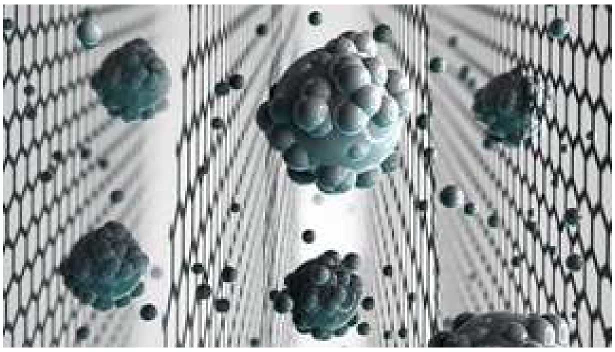
Ultrafiltration is another membrane process that uses physical separation and size exclusion to purify water in a mechanical process, but the Ultra can be misleading. In fact, while an RO membrane removes 90% of TDS (total dissolved solids), with a filter pore size of 0.0001 micron, a UF filter has a pore size of 0.01 micron. This allows for the passage of more products including salts, while keeping out viruses, bacteria, and larger contaminants. The primary difference then is the 'mineral retention', which makes UF very useful as a home water filtration system that retains minerals that are actually value, while not requiring the immense pressures of RO systems, and not creating a waste product. [31]

The applications for this technology therefore are useful as a filtration with less demands for the product water compared to the water source, meaning cleaner or without salts. Conversely, the technology can also be applied for wastewater treatment to provide some treatment and removal of contaminants without the high energy requirements and overkill of an RO process, provided there are no physical solids. It can be used in a 'tertiary' wastewater treatment process, with a pressure requirement of only 2.5 bar, compared to 35-62 bar in a desalination plant. [32]

UF is therefore not a direct replacement of RO systems, but can be a very useful addition as either pretreatment or for less energy intensive treatment of wastewater. Modular system deployments also make such units easier to combine with other systems to achieve the desired outcome.

Graphene & Carbon Nanotubes – Wonder Material?

Graphene, and specifically graphene oxide, have more recently made headlines for their potential use as a breakthrough material for use in desalination membranes, as well as a variety of other sectors. But how close are they to commercial reality, and being the go-to membrane material to desalinate water? [33] [34]



From covalent bonds to predicted atomic orbitals, what we know about carbon is that it can form highly strong bonds that produce materials that are extremely lightweight and extremely strong. Carbon fiber and diamonds are familiar examples, yet carbon can also form graphite used in pencil led, which is very weak and malleable. Graphene is 1-atom thin lattice structure of carbon in hexagonal covalent bonds, that looks a bit like chicken wire, but can be 100x the strength of steel with 1/20th the weight. The thinnest material ever created. This has driven a great deal of interest to apply it to everything from supercomputer chips to airplane and spacecraft, or desalination membranes. A distributed graphene solution in water could be used as a spray coating, using graphene oxide to apply a graphene as a coating. The rush to use this material has led to thousands of patents from China to the UK, or companies like Samsung. As is often the case with new technologies, the problem is scale.

Producing enough of the material in any 'economical' sense remains challenging, with limited amounts able to be currently produced, with their attending high costs. As is often the case from Algae biofuels to hydrogen or graphene, the hope is that with enough economies of scale to produce large quantities, this can supplant and replace current infrastructure that has been built up around fossil fuels of coal, oil and gas. However, industry inertia and the cost gaps between the lab and commercial scale have thus far proven too wide to cross.

Hydrogen Fuel Cells & Water Disassociation

Hydrogen Fuel cells are another emerging technology that have been thought of for decades and faced the same hurdles and caveats with any breakthrough story—the engineering and infrastructure obstacles need work. It is typically considered a periphery fuel. The technology in theory can produce wonders, powering cars and even major container ships, ferries, or trains, and is even being developed for airplanes. Japan has made a particularly large bet on the development of the Hydrogen economy emerging, as it seeks to diversify away from fossil fuels and be 'carbon-free' by 2050. The country plans to have 10% of electricity generation from hydrogen power, from 0% today, with a focus on steel manufacture and shipping sectors.

> *"Hydrogen has been hyped before, and there are still big economic and technical challenges to overcome." –WSJ [35]*

GE's Power & Aviation units are working to combine its gas turbine engine technology with hydrogen and hybrid systems that could be used for both power generation, as well as aircraft engines. With the aviation industry making 2% of global carbon emissions, this is another sector that must reform, but has so far had few viable alternatives. [36][37]

GE Hydrogen Gas Turbine Engine. Source: ge.com

The use of Hydrogen power from cars, buses, trains, to ferries is also being pursued with pilot projects around the world, including the summer Olympics games taking place in Japan. Hydrogen remains an intriguing option for many companies that could also be developed in a transitional phase, stored as liquid ammonia. It can be more easily integrated into current infrastructure while new innovations are deployed to have H2 become the dominate fuel source. [38] [39][40][41]

Another major industry is international shipping, a lifeblood of the globalized economy that is still physically limited by the sheer scale of the oceans they travel. It is also among of the most polluting industries, with a single container ship considered to be the equivalent in emissions of 50 million cars. [42]
Hydrogen fuel cells may be able to provide a solution, and even be able to take their own fuel needs directly from the sea. The US Navy and Google X research projects have looked into this before, and recent breakthroughs at Stanford University have shown promise to draw seawater and use renewable energy to create the hydrogen necessary to power such large engines.

Nuclear Desalination – 'One way to boil water'

Another process combining an energy source with desalination is nuclear desalination—which may seem like an excessive way to power such a process, but it is one with some advantages. Small modular nuclear reactors are enabling the use of smaller scale deployments of this technology, which is carbon-free and provides an abundance of power unmatched by any other renewable. The process is to use both the electricity and the heat generated by a nuclear power plant to remove salt and minerals from water, to produce freshwater, while also doing so in a way that protects it from any radiation or contamination of the freshwater produced.

With small modular systems, this can be deployed more easily with refueling being done roughly every 20 years. In a self-contained system design, they can also be safer as there is less to go wrong, and less reliance on external systems to contribute to cooling. Nuclear technology has largely stagnated in both its research and deployment since the 1980s, with the high-profile accidents of Three Mile Island, Chernobyl, and more recently, Fukushima. However, new plants are still being built, and countries like France already make up a large part of their energy mix from nuclear power. The Taishan Nuclear Power Plant in China is a joint venture of China and France to deploy the first of a newer EPR-type plant, which builds in four additional safety fail-safes, onto technology that is still largely from the 1980s. [43]

As is often the case, the technology that comes to dominate the market—light water reactors—may not be the best, but may be the most economical and readily available, driving out other competitors. This, as seen with Chernobyl, has helped to damage the reputation of the nuclear energy sector due to failures of some of the worst examples of the industry.

The Department of Energy in the United States is funding new companies including TerraPower, XEnergy, and in particular Nuscale, at grants of $80 million and $1.4 billion, to develop new modular small-scale nuclear reactor technology. Even companies such as Rolls Royce are working to deploy already proven technology in a small modular package that can be brought to market. [44][45]

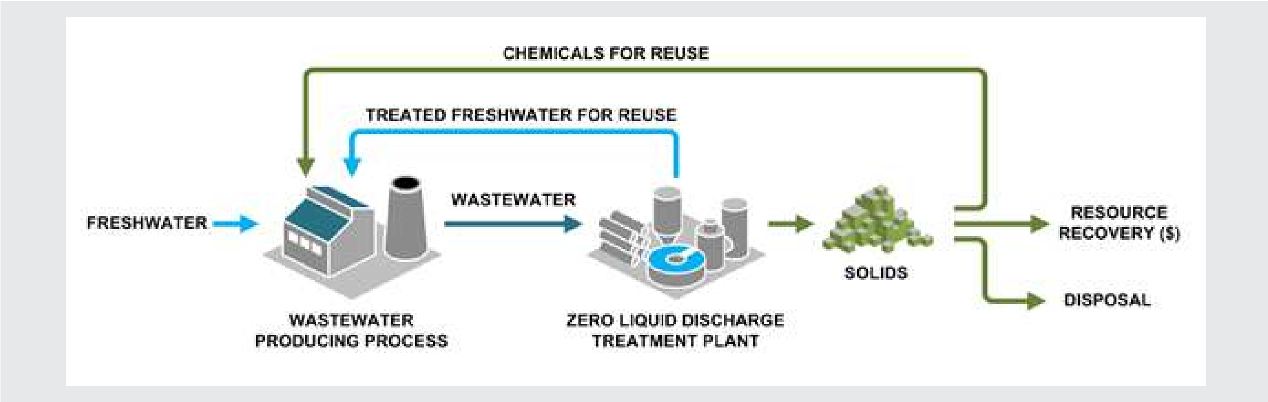
While nuclear has many drawbacks still beyond just perception, including the storage and/or recycling of spent nuclear fuel, it's positives cannot be overlooked in terms of a carbon neutral future as the rest of the world continues to develop and electrify. The cost of PV solar panels continues to fall, often leading the argument that nuclear is unnecessary and should be phase out. However, the sheer scale needed to deploy them in order to power ever-larger cities, plus the need for reliable base power loads for electric grids, makes nuclear a key component of future carbon-free mixed energy grids—working alongside wind, solar, hydropower, or hydrogen gas. Deploying these systems alongside water solutions can help to solve both water and energy problems in a way that is free of fossil fuels.

Wastewater Technology: Re-use & Energy recovery

For the treatment of wastewater, a great deal of innovation has progressed alongside the membrane and distillation processes used to desalinate seawater or brackish water into freshwater. Many of the same procedures and technologies are used to produce clean—or cleaner—water from wastewater. However, wastewater also presents its own unique challenges related to the sector and type of wastewater that is being produced. Leather tanneries, municipal waste, metals and mining, power plants, paper mills or olive mills, all present their own needs for water usage, and particular waste byproducts from their industry. A major factor of water pollution around the world is the mismanagement or simple lack of treatment for wastewater, from factories to homes.

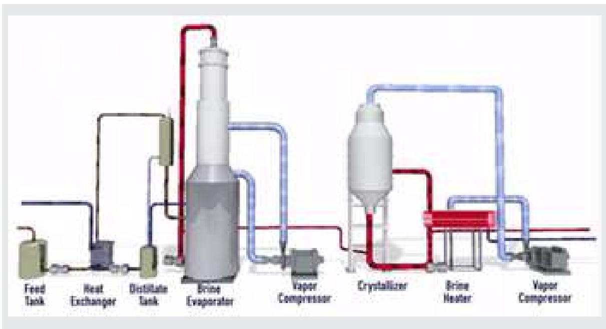
Industrial water applications have sought to address both ends of these challenges, by providing ultra-filtered water for microprocessors and pharmaceutical applications, or to deal with the waste products from mining, metals, or oil & gas operations. [46][47]

Ultrapure water (UPW) is key to the microelectronics manufacturing, and the cost of procuring this vital water directly impacts their cost, including from seawater or brackish sources. EDI or Electro-deionization is one such process to meet this end. However, as in many industrial applications, small-scale and energy intensive processes are acceptable to corporate bottom lines but would not be scalable or economical for municipal applications, or to provide water for agriculture. As mentioned, they key is the energy and its origins.



Zero Liquid Discharge (ZLD) – Wastewater Treatment

Using a series of heat exchangers and brine evaporators or concentrators, a feed water of wastewater can be recycled into highly pure water using heat and vapor compression and crystallizer. Through these series of steps water is extracted, turned to vapor, then compressed again into water, with the distillate created in the process able to be funneled back into the first heat exchange of the wastewater feed. [48]



Source: suezwatertechnologies.com

This process gives options to many industrial applications for dealing with their tough-to-treat wastewater feeds, allowing to both treat their wastewater, re-use the water extracted in the plant, and potentially make use of the crystals created from the brine, or where more typical wastewater discharge options are not available. It is particularly useful in semiconductor operations. Suez has also marketed this technology and approach as a means of addressing specific industrial regulatory challenges.

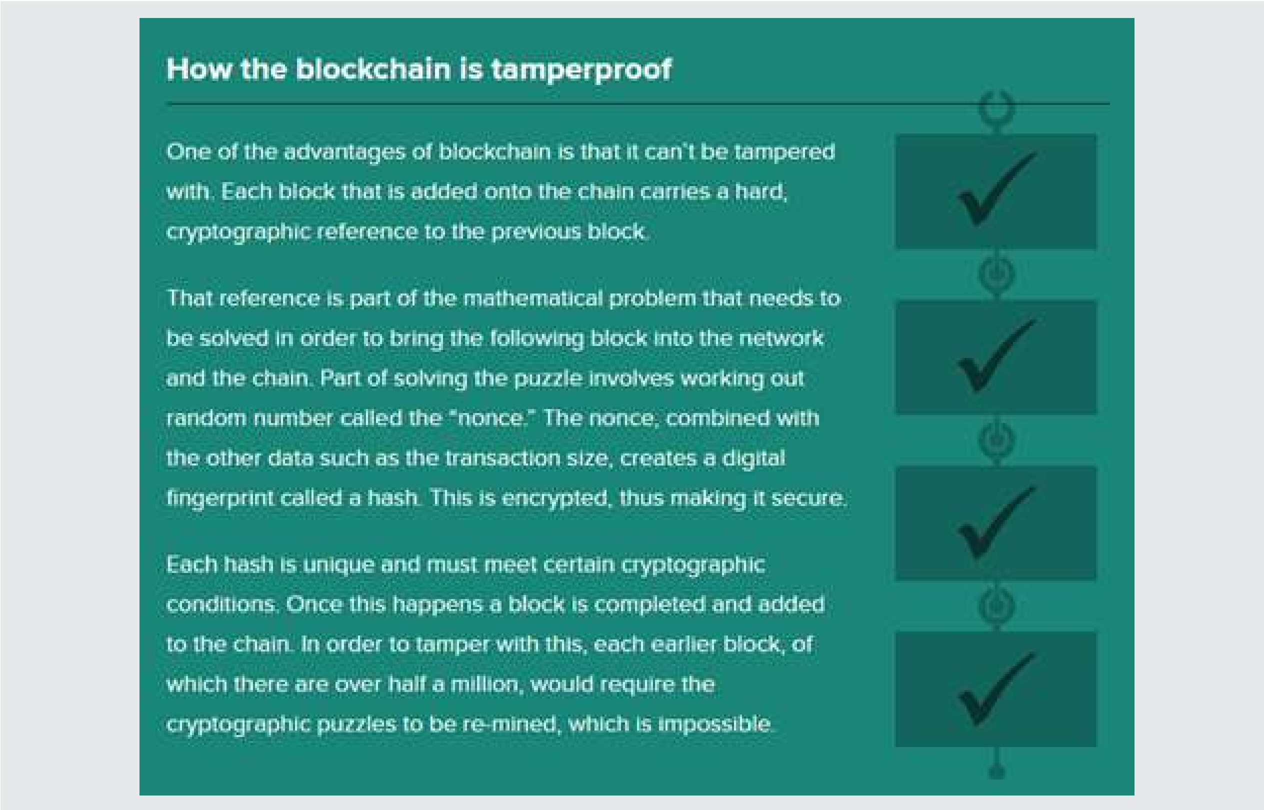
The obvious drawback is the additional power requirements necessary in these extra steps to extract the most from wastewater. Many industries will only pursue such cleaner options that come with their own costs, when required to do so by law and enforced regulations.

Blockchain: Useful product or fad?

One emerging technology that has made a lot of noise in recent years and months is that of Blockchain, specifically in relation to cryptocurrencies such as Bitcoin. While most have heard of the products or tools that run off of blockchain, like Bitcoin, fewer have heard about the blockchain itself and what it actually does. For a variety of sectors, speculation bubbles may come and go, but there is real value waiting to be deployed by addressing accounting and verification problems between entities.

As per CNBC, "the first major application of blockchain technology was bitcoin which was released in 2009. Bitcoin is a cryptocurrency and the blockchain is the technology that underpins it. A cryptocurrency refers to a digital coin that runs on a blockchain." The blockchain is the public record that is produced and maintained for every transaction, be it of a digital currency, or of water stock allocations, between riparians. The fact that this public record book is distributed—meaning copies are held in numerous other locations—increases its security, and each additional entry must agree with all past versions, so that it cannot be retroactively changed or cheated.

Using digital signatures and the techniques of cryptography, information can be tracked and balances updated without relying upon a central authority—addressing the verification problem between two entities. This aspect makes it of interest to transboundary water resource allocations. Understanding how the blockchain works with



Source: cnbc.com

products like Bitcoin or Ethereum will allow us to see how the technology can be transferred to many other 'real-world' use cases, such as water rights, real estate transactions, or secure sharing of medical data.

The appeal is towards increasing transparent governance, which could be envisioned in a conflict such as that of the GERD. For example, using remote sensing techniques to gather and/or independently verify data, track water resource allocations, enter this data into a distributed ledger, which is transparently maintained for all parties. If such objective and transparent data were made possible, it would be easier to enforce international agreements that are bound to the principles of international water law, such as the UN Watercourses Convention and the principles of No Significant Harm, and fair & reasonable use.

Technology vs Politics – The Political Limits of Technology

In the current 'information' age it can be comforting to think that technological advances will be able to solve the global challenges facing the human race today and into the future. Ranging from economic development to public health, or climate change, we need only to design and develop our problems away. Plastics will be recycled, waste will be converted and reused, and little will be asked of us individually to change our lifestyles or be inconvenienced.

The unfortunate reality however is both more complex and simpler. The reality of recycling materials, of being carbon negative, and scaling up promising new technologies is more complex than we often appreciate. Many solutions and alternatives that should be options in theory, have not proven to be so in practice. A simpler solution is often readily available to us but requires some difficult choices that many societies and governments do not want to make. [49]

As presented above, many of the technologies that are being relied upon today, are in fact refinements of methods or processes developed decades or even centuries ago. While breakthroughs that are just around the corner, have been around the corner for several decades. Some may indeed break through and reach commercial success—but these are more often the exception rather than the norm. This is often not just about the tech itself, but about the industry around it, and the inertia of current systems.

Researchers estimated that there has not been this much carbon dioxide in the atmosphere for at least 3 million years
Source: Sascha Steinbach/EPA via shutterstock

Graphene may revolutionize the water sector, or it may be a niche material used in highly specific applications where its costs can be justified compared to readily available alternatives. Hydrogen fuel cells, 3rd generation biofuels, or next-generation synthetic algae technologies could revolutionize sectors from transit to agriculture, or they may be more simply replaced by swapping gasoline for electric cars and updated electrical grids, and gas pumps for charging stations.

External factors always effect what technologies are adopted, versus what is technically the 'best' or most advanced. Economies of scale, commercialization, and the dislocation of entrenched interests can greatly delay or prevent the overhaul of already well-established sectors. In a word, politicization influences technological advancement, and innovation will not save us.

As it relates to transboundary water conflicts and wider issues like climate change, mitigation and reduction still offer the most direct impacts on improving transboundary environmental issues. While adaptation is becoming more and more necessary, it cannot be relied upon solely, as the long-run timeline of its implementation does not align with the needs of the earth. As economies start to emerge from the pandemic, so are emissions to ever more unprecedented levels, with carbon levels at the highest in recorded history. [50]

Politics cannot be removed from technology, as the areas we choose to invest in, subsidize, or protect, determine the path of technological innovation by influencing the market for what is possible. How government choose to interact with technologies and support or hinder their success has profound impacts that cannot be ignored. Technology does not exist in a vacuum, and adoption is driven by policy. Similarly, the historical inertia of industries and their interests, and the support they have received in the past, must also be kept in mind when considering the viability of a new technology for commercial success. For countries, this also requires balancing national security interests with global stewardship.

Negative externalities, such as the environmental impacts of burning fossil fuels, have not been historically taken into account when developing industries, including energy or even water. What is most efficient or cost-effective to the market depends on the time scale and the number of factors considered. As such, a fair comparison of a 'costs per liter' for a new technology versus legacy systems is not usually so straightforward. Including the costs of future climate change impacts or inevitably necessary adaptation measures changes the calculus for a liter of fuel, or a cubic meter of water.

In spite of historic highs for monthly or annual temperatures, or CO2 levels in the atmosphere, subsidies for fossil fuels remain large, and new major projects are being built around the world. [51][52]

Debates on subsidies for new technologies—and their commercial viability without them—must be had. However, without a true and full accounting of costs, subsidies, and externalities, governments and people cannot make informed decisions about the right technologies to adopt or support.

Technology is ultimately a tool, and the toolbox made available to us is a political decision. Regardless of the tools, the global transboundary problems we must address remain the same, and will require shared solutions, technology transfers, and negotiated agreements.

It is imperative that nations to not resign themselves to the assumption that technology will save us, or that we can innovate our way out of global environmental problems, particularly when it is a race against time. Technology and innovation will be critical and become more necessary by the day. However, mitigation and cooperation remain our most readily available tools to combat transboundary environmental problems from water security to climate change. [53]

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Sources for Further Learning

Carbon Mapper

https://carbonmapper.org/

ESRI – GIS Training

https://www.esri.com/training/catalog/57630434851d31e02a43ef28/getting-started-with-gis/

NASA EarthData – Open Access for Open Science – What is Remote Sensing?

https://Earthdata.nasa.gov/learn/backgrounders/remote-sensing

NASA – Water Practitioner Resources

https://appliedsciences.nasa.gov/what-we-do/water-resources/practitioner-resources

Scripps Institution of Oceanography at UC San Diego – Global Atmospheric Carbon Dioxide Concentration

https://keelingcurve.ucsd.edu/

USGS – United States Geological Service – FAQs on Mapping, Remote Sensing, and Geospatial Data

https://www.usgs.gov/faq/mapping-remote-sensing-and-geospatial-data#

World Wildlife Fund – HydroSHEDS

https://www.worldwildlife.org/pages/hydrosheds

Briefs in the Series

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Issue 6 - Transboundary Dams
Issue 7 - International Water Law
Issue 8 - Gender and Transboundary Water
Issue 9 - Transboundary Water Technology

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Acknowledgements

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