Water Connections

Communities, Ecosystems & Water

The content in this document is intended to provide a downloadable, paper-based equivalent to the content on the Canada WaterPortal web site for the second edition of the Water Connections project. Our web site contains additional informative and illustrative graphics and is more user friendly however, we recognise that not everyone has access to the internet and some may prefer to work from a paper document.

Regardless of how you access our content, we hope you find it informative, and that it helps in your understanding of the interconnected nature of communities, ecosystems and water.

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Canada WaterPortal

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Delivering a project of this size, over 33,000 words, is not possible without the time and efforts of many people and organisations. We could not have done this without the generous support, guidance and hard work of the following people:

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Intent

The purpose of this project is to provide useful and engaging content, grounded in publicly accessible references, informing readers about a resource critical to our communities and ecosystems: water.

It is our hope that you enjoy this content and the associated crossword puzzles, word searches and roll-and-write game that are freely available via our web site.

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Water Wise: Educating for Smarter Use

Water is an essential resource for all forms of life. Despite its critical importance, water is often taken for granted, and its sustainable management is often overlooked. Canada is home to over 2 million lakes and rivers. Building community awareness and education about water is vital for fostering responsible water use and ensuring the sustainability of this precious resource. This is the introduction to a collection of articles to enhance community awareness and education about water, highlighting the roles of schools, local governments, community organizations, and individual actions.

Understanding the Importance of Water Education

Water education involves learning about the sources, uses, and conservation of water. It helps individuals and communities understand the significance of water in their daily lives and the broader environment. Effective water education can lead to informed decision-making, promoting water conservation, sustainable practices, and water security [1]. By raising awareness about water issues, communities can better address challenges such as water scarcity, water pollution, and climate change impacts.

The United Nations' 2024 World Water Development Report outlines the growing gap between the severity of water problems, knowledge and skills needed to properly address them. Promoting water education and awareness among future decision makers, will lead to positive global change.

The Report notes that there are 1.2 billion people in the world between the ages of 15-24, with that number expected to grow by 7% in the coming 6 years. This reinforces the importance of educating young people about water problems, and the need to address them.

1. UNESCO, 2023, United Nations World Water Development Report p142. https://unesdoc.unesco.org/ark:/48223/pf0000384655. Accessed 2024-07-17.

A Multi-layered Effort

Coordination and cooperation between the government, non-governmental organizations (NGOs), and communities is key to promoting awareness and water education. This collaboration allows for deeper analysis and clearer data communication to inform individuals and the community.

Government

Local government and legislative bodies are important to developing community awareness of water issues and water education. It is their responsibility to create, monitor, and promote laws and regulations which act to increase awareness and protect water. Governments may also have the mandate and be able to access greater resources and specialist expertise to conduct resource-intensive research projects. There can, however, be challenges for the public in obtaining access to the results of the research.

Since governments can encourage and enforce conservation strategies through legislation and policies, they are well positioned to promote the long-term success of water awareness and education and sustainability practices. This will be explored further in the following sections.

Non-Governmental Organisations (NGO's), Schools, and Post-Secondary Institutions

NGO's and education institutions are among the most crucial groups for the promotion of water awareness. These organizations can interpret the data provided by governments and present it to the public and the Canadian youth. These groups can act as the bridge between governments and the community.

Water-focused NGOs share a common core goal of positive environmental progress. These groups are made up of dedicated people who enact community projects and can provide the volunteer (and sometimes financial) support needed to sponsor initiatives aligned with their water- focused values.

Kindergarten to Grade 12 schools and teachers play a fundamental role in the education of youth about water awareness and sustainability. Getting children and teens interested and active in water issues fosters a new generation of proactive,

water-aware decision makers. There are many ways to achieve this, both in and outside the classroom. Specific initiatives will be outlined in the following sections.

Post-secondary institutions play a crucial role in promoting water awareness by serving as hubs for research, education, and community engagement. Through innovative research programs, they advance our understanding of water scarcity, pollution, and conservation technologies. Academic and technical institutions also integrate water-related issues into their courses, teaching students how to address global water challenges. By hosting public lectures, workshops, and outreach initiatives, universities foster a broader dialogue about the importance of sustainable water management.

Communities and Individuals

Communities and individuals play a pivotal role in the promotion of water education by actively engaging in and advocating for sustainable water practices. Community groups often lead initiatives such as water conservation workshops, clean-up drives, and educational campaigns that highlight the importance of protecting water resources. By participating in these activities, individuals not only gain a better understanding of water issues but also inspire others to take action. Grassroots efforts are particularly powerful, driving change by fostering a culture of conservation and encouraging responsible water use at the local level. Individuals can contribute by adopting water-saving habits in their daily lives, supporting policies that promote water sustainability, and using their platforms to raise awareness about water-related challenges. Through collective efforts and personal commitment, communities and individuals can foster an informed and proactive society.

Water-awareness initiatives

In recent Canadian history, there have been varying initiatives led by governments, NGO's, and schools which impact communities and are united in their goal of achieving greater water awareness. Outlined below are some strategies.

International, National and Sub-National Water Policy and Strategy

There are many water-related initiatives at the international, national and sub-national levels. What follows is an example from each level.

International: UNESCO

While UNESCO is not officially a governmental organization, it is an arm of the United Nations (UN). The UN is an international organization focused on global peace and security and involves the cooperation and collaboration of governments all over the world. UNESCO works to promote peace and development through education and science, and is heavily involved in the water world, specifically the 6th of the UN's Sustainable Development Goals [2].

This organization is a world leader in promoting awareness and education on water issues and sustainability, and with their vast resources, can positively influence the geopolitical landscape.

National: Canada Water Agency

In 2023, the Government of Canada passed legislation establishing the Canada Water Agency [3] as an independent entity promoting freshwater management. The Canada Water Agency works closely with federal and provincial/territorial departments and Indigenous Peoples.

Sub-national: Alberta Water Act

Most recently updated in 2000, the Alberta Water Act and its associated Regulations are the foundation of water governance throughout Alberta. This includes the sharing, distribution, accessing and protection of water. This Act is the legal framework passed by the legislature that describes how individual Albertans, all organisations and Alberta governments interact with water. The Act and its associated regulations are the rules that outline rights and responsibilities relating to provincial water and address topics such as ownership, diversion licenses, priority of access to water, and penalties resulting from violating the Act and related Regulations.

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2 United Nations, n.d., Ensure availability and sustainable management of water and sanitation for all. https://sdgs.un.org/goals/goal6. Accessed 2024-07-15.

3 Government of Canada, 2024, Canada Water Agency. https://www.canada.ca/en/environment-climate-change/services/water-overview/canada-water-agency.html. Accessed 2024-07-17.

While the Alberta Water Act only applies inside Alberta, each province and territory has its own equivalent legislation and regulations.

Educational Programs – NGO's and schools

Water Education programs for schools

The following programs are examples of ways organizations have worked to educate Canadian youth on water and sustainability.

Inside Education – Water Literacy in Alberta K-12 Schools

Inside Education offers in-depth water education programs assisting teachers in promoting water literacy through science. Curriculum-connected classroom presentations, outdoor wetland field trips, one-day Water Innovation Day field trips, and high school youth leadership summits all focus on water management, human impact, and Alberta-based innovations. They also have professional development trips available for teachers to hear from multiple perspectives on water issues in Alberta.

Meewasin Valley Authority

Located on the South Saskatchewan River as it passes through Saskatoon, the Meewasin Valley Authority works to promote a healthy and vibrant river valley, and conservation strategies. They offer trail hiking tours, led by professionals who emphasize the importance of conservation strategies. They also offer summer camp opportunities, through "theme weeks" which include "Creek Creativity" and "Wandering & Wayfinding" [4].

Project Water Education for Teachers (WET)

Project WET is an organization which uses hands-on learning experiences to instill environmental responsibility at a young age. They provide learning and training tools for teachers and experiential learning activities for students.

Online databases easily accessible to teachers and students

Canada WaterPortal Society

One of the services offered by the Canada WaterPortal Society (That's us!) is a website hosting information, projects, and learning resources surrounding water

4 Meewasin Valley Authority, 2024, Eco-Adventure Camps. https://meewasin.com/ecoadventure/. Accessed 2024-07-30.

issues in Canada. The website features conservation strategies, types of infrastructure and irrigation, governmental roles, and water as it relates to different environmental crises.

The WaterPortal hosts resources for teachers within classrooms and helps to develop water-based curricula. The website is also accessible to students, who can independently explore topics of interest.

World Wildlife Fund

The World Wildlife Fund (WWF) is a public source of information promoting good water governance, protecting water ecosystems, and restoring degraded rivers, lakes, and wetlands.

Trout Unlimited

Trout Unlimited is a registered Canadian charity who focus on the conservation and protection of Canadian freshwater ecosystems. They are also heavily involved in conservation education and are led by professional, action-oriented staff members.

Ducks Unlimited

Akin to Trout Unlimited, Ducks Unlimited is a charity focused on habitat conservation across all Canadian wetlands and have been proud stewards of these wetlands since 1938.

Nature Conservancy of Canada

The Nature Conservancy of Canada Is one of Canada's leading charities focused on land and nature conservation, with a focus on long-term and large-scale solutions across the country.

The Gordon Foundation's DataStream

DataStream is an open access platform for Canadians to share water data from across the nation. Within the site are "hubs" specific to different regions and watersheds throughout the country. Citizen science projects like this promote awareness on water issues, provide a platform for observations, and stimulate conversation.

One of the features of their site is an easy-to-use interactive map which outlines all the data reports, organized by location. This map is an example of just how many people across the country take part in reporting these statistics, indicating a

collective desire among Canadians to promote public databases and access to environmental statistics.

Technology and Innovation

Virtual tools

The Covid-19 pandemic forced many organizations to switch to virtual activities. Educational organizations such as universities and high schools began implementing E-learning tools, improving their accessibility and functionality [5]. Governments and professional organizations also transitioned research and data online resulting in greater public access. It is important that these virtual tools are maintained and evolve for public benefit.

Artificial Intelligence in Water Education and Awareness

Artificial Intelligence (AI) is transforming water education and awareness by providing innovative tools for data analysis, predictive modeling, and personalized learning. AI-driven platforms can analyze water-related data to predict trends, identify risks, and optimize resource management, making it easier for educators and policymakers to understand and address water issues. For example, machine learning algorithms can detect patterns in water usage and pollution, enabling targeted conservation efforts. AI-powered educational tools, such as interactive apps and virtual reality simulations, offer engaging ways for individuals and communities to learn about water conservation and management. Additionally, AI can enhance public awareness through chatbots and digital assistants that provide real-time information and answer questions about water conservation practices. These advances make water education more accessible and impactful by using technology to deliver timely and relevant information.

Social Media

The evolution of the internet and its leading applications has created a world of constant connectivity. Social media platforms, in particular, have become a significant source of news due to their ability to share information rapidly. A study

5 UNESCO, 2023, United Nations World Water Development Report p. 142-143. https://unesdoc.unesco.org/ark:/48223/pf0000384655. Accessed 2024-07-17.

done in 2021 found that nearly half of Americans use social media to access their daily news [6]. In Canada, a 2023 survey showed that 84% of people aged 15-34 gained their news or information from social media or the internet. This number drops to 65% among those aged 35 – 54 and less than 20% among those aged 65+ [7].

However, this accessibility often comes at the cost of accountability, fueling the rapid spread of misinformation. While this poses a serious concern, the power, influence, and global reach of social media cannot be ignored. It is an extremely useful tool that can inform millions of people across the globe. For initiatives such as promoting water awareness, social media can be highly effective—provided factual accuracy, credibility, and critical evaluation remain at the forefront, supported by transparent strategies and honest communication.

Interconnectivity and Long Term Strategies

One often-overlooked outcome of education is it's ability to inspire lifelong learning. Water and its inherent topics and issues are all tightly interconnected, and it is difficult to learn about one topic without stumbling over another. It is important to reinforce this interconnectivity to the youth in schools since they are among the most creative in our society. By nurturing this creativity and equipping them with a strong foundation of knowledge, the next generation is empowered to become leaders in addressing the challenges and opportunities within the water world.

One of the major goals of water education is the promotion and furthering of social equity. Ensuring equitable access to water resources is a crucial step in the development and progress of a just society. By enhancing water education and awareness, we can spread awareness of inequities in our society, at the governmental level, organizational level, and within our communities. Ensuring that the next generation of leaders are aware of this is how we support diversity and inclusion for all.

6 Pew Research Center, 2021, News Consumption Across Social Media in 2021. https://www.pewresearch.org/journalism/2021/09/20/news-consumption-across-social-media-in-2021/. Accessed 2024-07-17.

7 Statistics Canada, 2023, Canadian Social Survey - Quality of Life, Virtual Health Care and Trust, 2023. https://www150.statcan.gc.ca/n1/daily-quotidien/231110/dq231110b-eng.htm. Accessed 2024-12-04.

For sustained impact, communities must develop long-term water conservation strategies. This involves periodic monitoring and evaluation to measure the effectiveness of implemented programs and practices. Local governments can set up water conservation committees made up of representatives from various stakeholder groups to oversee these efforts. Continued efforts from NGO's (e.g. the Alberta Watershed Planning and Advisory Councils) and schools to reinforce awareness and education initiatives is necessary, with the communities and individuals in mind.

Water is our most important resource, capable of creating and destroying. It is critical to continue to build on the existing strategies for water management and education. We must also adapt to the changing times with powerful new digital tools and ensure that water education can be accessible to as many people as possible.

Conclusion

This project, Water Connections 2: Communities, Ecosystems and Water, delves into the vital role water plays in linking communities and ecosystems, as well as the ways communities impact both water and ecosystems. We hope that you will find this exploration both engaging and interesting as you continue your learning journey.

Biodiversity Loss

Biodiversity: The Foundation of Ecological Balance

Biodiversity is a broad term referring to all life forms found on our planet, including different plants, animals, and microorganisms, as well as the ecosystems they live in such as forests, oceans, and deserts. Biodiversity has three separate definitions. It can mean variety within a species, such as the genetic diversity found within the white spruce species" Biodiversity can also mean the variety between species in an area, such as how many different species live in the boreal forest. Lastly, biodiversity can refer to the variety of biological communities and habitats in an area, such as how the boreal forest itself is made up of different stands of trees, different types of wetlands and water bodies, etc.[8]

This variety is important because it helps ecosystems stay resilient, meaning they can better handle changes or threats like climate change, natural disasters, or harm caused by humans[9]. Every organism, big or small, is important in keeping the environment balanced, which is also important for human survival. The number of species on Earth is still unknown, but in 2011, estimates ranged from 8.7 million to 100 million, with 18,000 new animal species discovered each year[10]. We rely on diverse species and ecosystems for food, clean water, and medicine. Understanding how nature is connected helps us identify ways we can protect those connections and keep our planet and communities healthy.

The Role of Water in Maintaining Biodiversity

Water is essential for our planet and for supporting biodiversity across the Earth. It's a key resource that supports ecosystems, economies, and societies. Water helps create and maintain living spaces for all kinds of life and plays a crucial role in

[8] Hancock, L., n.d., What is biodiversity? https://www.worldwildlife.org/pages/what-is-biodiversity. Accessed 2024-03-11.

9 Cleland, E. E., 2011, Biodiversity and Ecosystem Stability. https://www.nature.com/scitable/knowledge/library/biodiversity-and-ecosystem-stability- 17059965/. Accessed 2024-09-10.

10 Thompson, J., 2023-10-08, How many animals have ever existed on earth?. LiveScience. https://www.livescience.com/animals/how-many-animals-have-ever-existed-on-earth. Accessed 2024-03-11.

controlling climate, moving nutrients, and helping species survive and interact[11]. The connection between water and healthy biodiversity ensures that ecosystems like wetlands, forests, and coral reefs can clean and control water, for continued use by all living beings.

However, if water quality or availability changes, it can negatively affect life, causing environments to degrade and species to disappear. The relationship between water and biodiversity is mutual; a diverse natural world helps keep water clean and available, supporting a variety of life. Communities worldwide depend on this natural balance for food, medicine, and recreation.

Community Partaking in Nature-Based Solutions

The relationship between humans and nature is deeply interconnected, highlighting how essential biodiversity and water are to our lives. Biodiversity brings a wide range of benefits; it supports agriculture, health, and the environment[12]. If biodiversity or water sources are jeopardized, it can lead to problems such as food shortages, health and hygiene issues, and weakened economies.

Protecting nature isn't just about conservation for the future; it's crucial for the current functioning of societies across the world.

Communities can take part in protecting biodiversity by implementing nature-based solutions, which focus on working with natural processes rather than relying on human-made infrastructure. Activities such as planting trees, reconnecting rivers to their floodplains, and restoring wetlands can help rebalance the water cycle and mitigate the effects of climate change[13].

11 National Oceanic and Atmospheric Administration, 2013-06-21, How does the ocean affect climate and weather on land? https://oceanexplorer.noaa.gov/facts/climate.html. Accessed 2024- 09-10.

12 Nature Saskatchewan, 2006-01, The value of biodiversity to farming on the prairies. https://www.naturesask.ca/rsu_docs/faming-and-biodiversity.pdf. Accessed 2024-03-11.

13 United Nations Climate Action, 2020-10-16, Biodiversity and nature-based solutions. https://www.un.org/en/climatechange/climate-solutions/biodiversity-and-nature-based- solutions. Accessed 2024-12-12.

Biodiversity Decline

Climate change and human actions are causing a rapid loss of biodiversity. The burning of fossil fuels and the destruction of forests and other habitats are raising Earth's temperatures and changing the environments in which many species have evolved to survive[14]. These changes lead to unstable weather patterns and make it hard for many species to survive, causing them to migrate, evolve, die off in areas they previously lived in, or become extinct[15].

At the same time, activities such as building and farming damage the natural world by breaking up habitats and leaving less room for wildlife. As our environment continues to change – with rivers drying up, forests and wilderness areas getting smaller, and oceans becoming more acidic – it's clear we need to act quickly. To secure the ecosystem services such as air and water purification, waste decomposition and soil fertility, we must work together to reduce climate change and protect natural habitats.

In addition to the directly human-caused pressures on habitats, the climate is changing. As the climate changes, species are being stressed as their environment changes. Some species are moving to new areas which adds to the pressure on the species and food chains already in those areas.

As mentioned above, nobody knows for sure how many species there are on the planet. However, we do know that the populations of many known species are dropping. The figure below shows that almost 32,000 populations of 5,230 species decreased by an average of 69% between 1970 and 2018.

Examples of Biodiversity Loss in Canada

- **Wetlands Destruction**:
  Threatened by urbanization, agricultural expansion, and pollution, Canada's

14 Defenders of Wildlife, n.d., Combating climate change. https://defenders.org/issues/combating- climate-change. Accessed 2024-09-10.

15 International Fund for Animal Welfare, 2023-08-09, Which animals are most impacted by climate change? https://www.ifaw.org/ca-en/journal/animals-most-impacted-climate-change. Accessed 2024-12-15.

wetlands are losing their ability to support diverse species, filter water, and control floods16.

- **Arctic Biodiversity Changes**:
  Rapid environmental changes in Canada's Arctic, like ice loss and permafrost thaw, endanger species like polar bears, seals, and migratory birds reliant on saltwater and freshwater habitats17.
- **Salmon Populations Decline**:
  Canadian salmon species like sockeye, chinook, and coho face declines due to overfishing, habitat destruction, pollution, and migration barriers such as dams, affecting the broader aquatic ecosystem[18].
- Blanding's Turtles in the Great Lakes and Nova Scotia are threatened by habitat loss, road mortality, reduced prey, and pollution19.
- Polar Bears are losing their habitats due to changes in historical weather patterns and sea-ice loss from climate change20.

However, it is not all doom and gloom. There have also been conservation successes in Canada.

- The reintroduction of Swift Fox in the 1980s after near extinction in the 1930s in the Prairies has led to a growing population21.
- The Sea Otter population has rebounded in British Columbia after being almost destroyed by the fur trade22.

16 Gloutney, M., 2023-02-03, Canada's wetlands are critical to ecosystem recovery, according to national director at DUC. https://environmentjournal.ca/canadas-wetlands-are-critical-to- ecosystem-recovery-according-to-duc/. Accessed 2024-03-11.

17 Arctic Council, n.d., Safeguarding Arctic Biodiversity. https://arctic- council.org/explore/topics/biodiversity/. Accessed 2024-03-11.

18 United States Environmental Protection Agency, 2023-09-15, Chinook Salmon. https://www.epa.gov/salish-sea/chinook-salmon. Accessed 2024-03-11.

19 Nature Conservancy Canada, n.d., Blanding's turtle. https://www.natureconservancy.ca/en/what- we-do/resource-centre/featured-species/reptiles-and-amphibians/blandings-turtle.html. Accessed 2024-09-10.

20 Centre for Biological Diversity, n.d., Saving the polar bear. https://www.biologicaldiversity.org/species/mammals/polar_bear/. Accessed 2024-03-11.

21 Nature Conservancy Canada, n.d.-b, Swift Fox. https://www.natureconservancy.ca/en/what-we-do/resource-centre/featured-species/mammals/swift-fox.html. Accessed 2024-09-10.

22 British Columbia Ministry of Environment, Lands and Parks, 1993, Sea otter. https://www2.gov.bc.ca/assets/gov/environment/plants-animals-and-ecosystems/species- ecosystems-at-risk/brochures/sea_otter.pdf. Accessed 2024-03-11.

- Wood Bison populations have grown and expanded through translocation projects23.

Social Consequences of Biodiversity Loss

Biodiversity loss has profound impacts on social equity, which refers to fair access to resources and opportunities within societies. Here's how these two are interconnected:

- **Access to Resources**:
  Biodiversity loss can disproportionately affect marginalized and vulnerable communities that rely more directly on natural resources for their livelihoods and well-being. These communities often depend on forests, fisheries, and other natural habitats for food, fuel, and income. When biodiversity declines due to factors such as deforestation, overfishing, or pollution, these communities lose the resources they need, which can make poverty and inequity worse[24].
- **Environmental Justice**:
  Biodiversity loss is often linked to environmental injustices. This happens when certain communities, especially those that are already disadvantaged, face more pollution and environmental damage than others' environmental degradation and pollution. These disadvantaged communities, or "marginalized communities", may face discrimination, poverty, or lack of access to things like education, reliable healthcare, or healthy food. Marginalized communities may be more likely to live near industrial sites, waste disposal facilities, or areas with high levels of pollution, putting them at greater risk of exposure to toxins and pollutants that harm biodiversity and human health[25]. Alternatively, industrial sites or waste disposal facilities might be more likely to be built near existing marginalized communities, since those

23 Environment and Climate Change Canada, 2020-10-15, Wood bison in Canada. https://www.canada.ca/en/environment-climate-change/services/species-risk-education- centre/wood-bison.html. Accessed 2024-03-11.

24 McCarthy, J., 2020-09-09, Biodiversity Loss threatens the world's poorest people most: Report. https://www.globalcitizen.org/en/content/living-planet-report-biodiversity/. Accessed 2024-12-12.

25 Brockie, J., & Han, S., 2023-08-10, Opinion: Environmental racism and Canada's wildfires. https://canadiangeographic.ca/articles/opinion-environmental-racism-and-canadas-wildfires Accessed 2024-03-11.

communities might not have the same political weight to prevent high polluting industries from building in their neighbourhoods[26].

- **Loss of Traditional Knowledge**:
  Indigenous Peoples and local communities often hold valuable traditional knowledge about their local ecosystems and biodiversity conservation practices that have been passed down through generations. However, when local ecosystems are disrupted, people lose the resources they need to continue using or teaching this traditional land-based knowledge. Over time, the loss of connection to nature can also mean the knowledge itself is forgotten or no longer passed down to younger generations. Ultimately, this can lead to undermining the cultural identity and self- determination of Indigenous Peoples and local communities. This loss of traditional knowledge can further exacerbate social inequities and contribute to the marginalization of these communities[27].

When addressing biodiversity loss, it's important to consider and prioritize concern for social equity. Conservation efforts should include and benefit all social groups. This approach not only protects biodiversity but also contributes to a fairer and more equitable world.

Pollution's Role in Biodiversity Loss

Pollution is the presence of any harmful substance that can cause damage to air, water, soil, and living things. Major sources of pollution are chemicals, plastics, and waste. These pollutants damage habitats, contaminate water, and disrupt the balance of life, which species need to survive. This results in less diverse and rich ecosystems. A loss in biodiversity doesn't just mean fewer plants and animals: it also weakens ecosystems, making them less capable of providing the services humans rely on.

Fighting pollution is crucial not only for protecting nature but also for preserving the basic conditions necessary for life.

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26 Liddie, J.M., Schnaider, L.A. & Sunderland, E.M., 2023, Sociodemographic Factors Are Associated with the Abundance ofPFAS Sources and Detection in U.S. Community Water Systems. https://pubs.acs.org/doi/epdf/10.1021/acs.est.2c07255?ref=article_openPDF. Accessed 2024-12-12.

27 Powless, B., 2023-01-16, How Indigenous Peoples are leading the way on Global Biodiversity Protection. https://canadiangeographic.ca/articles/how-indigenous-peoples-are-leading-the- way-on-global-biodiversity-protection/. Accessed 2024-03-11.

How pollution can harm water-related biodiversity:

Chemical Contamination:

Chemical pollutants, such as pesticides, heavy metals, and industrial run-off, can poison aquatic wildlife. These contaminants can accumulate in the bodies of aquatic organisms, causing illness or death, and can biomagnify in the food chain, affecting predators and prey[28].

Nutrient Pollution:

Excessive nutrients from agricultural runoff or sewage discharges can lead to eutrophication[29] (see also our page on eutrophication). This process causes dense growth of plant life and death of animal life from lack of oxygen, known as hypoxic or "dead zones," where no fish or typical marine life can survive[30].

Plastic Pollution:

Plastics can entangle wildlife or be ingested, leading to injury, illness, or death. Microplastics, or small pieces of plastic under 5 millimeters in length, can be ingested by a wide range of organisms, from small invertebrates to large mammals, and can carry toxins into the food web[31].

Thermal Pollution:

Discharges of warm water from industrial processes can alter the temperature of water bodies.

Many aquatic species have a limited tolerance for temperature change, so even small alterations can stress aquatic life, sometimes leading to decreased fertility, increased vulnerability to disease, or death[32]. A further complication is that

28 Sigmund, G., Ågerstrand, M. et al, 2023-04-08, Addressing chemical pollution in biodiversity research. https://doi.org/10.1111/gcb.16689. Accessed 2024-12-12.

29 Wageningen University & Research, 2023-08-18, Successful protection of biodiversity requires adequate pesticide and nutrient pollution indicators. https://www.wur.nl/en/newsarticle/successful-protection-of-biodiversity-requires-adequate- pesticide-and-nutrient-pollution-indicators.htm. Accessed 2024-03-11.

30 United States Environmental Protection Agency, 2023-11-29, Nutrient Pollution: The Effects: Environment. https://www.epa.gov/nutrientpollution/effects-environment. Accessed 2024-03-11.

31 Myers, J., 2023, Microplastics in the food chain: How harmful are they?. https://www.weforum.org/agenda/2022/06/how-microplastics-get-into-the-food-chain/. Accessed 2024-03-11.

32 Mishra, S., Ghosh, A., Rai, K., Jaiswal, B., Yadav, D. S., Agrawal, M., & Agrawal, S. B., 2021, Dimensions of climate change and its consequences on ecosystem functioning. https://doi.org/10.1016/b978-0-12-822928-6.00003-4. Accessed 2024-09-10.

warmer water cannot hold as much dissolved oxygen as colder water[33] which can, for example, threaten fish survival.

Sedimentation:

Erosion from wildfires, construction, mining, or agricultural activities can increase the amount of sediment in water bodies. This can smother habitats (such as spawning grounds), reduce light penetration (which affects photosynthesis in aquatic plants), and disrupt the feeding and respiration of fish and other aquatic life[34].

Acidification:

Acid rain, a byproduct of burning fossil fuels, can decrease the pH of water bodies, leading to acidification. This change in acidity can harm aquatic plants and animals, particularly those with calcium carbonate shells or skeletons, such as mollusks and corals[35].

Oil Spills:

Oil spills can coat everything they touch, making it impossible for marine animals to breathe or ingest food. Oil can also smother plants and, as it breaks down, release toxins into the water that can persist for the long term, causing chronic health problems in aquatic organisms[36].

Noise Pollution:

Underwater noise pollution from ships, sonar, and construction can be harmful to aquatic life, especially species like whales and dolphins that rely on echolocation for communication, navigation, and foraging[37].

33 United States Geological Survey, 2018, Dissolved Oxygen and Water. https://www.usgs.gov/special-topics/water-science-school/science/dissolved-oxygen-and-water. Accessed 2024-12-12.

34 Sun, Z., Brittain, J. E., Sokolova, E., Thygesen, H., Saltveit, S. J., Rauch, S., & Meland, S., 2018, Aquatic biodiversity in sedimentation ponds receiving road runoff – what are the key drivers? https://doi.org/10.1016/j.scitotenv.2017.06.080. Accessed 2024-03-11.

35 Gronlund, K. (2022, December 5). As acidification increases, ocean biodiversity may decline. https://futureoflife.org/recent-news/as-acidification-increases-ocean-biodiversity-may-decline. Accessed 2024-03-11.

36 National Oceanic and Atmospheric Administration, 2019-03-14, How does oil impact marine life?. https://oceanservice.noaa.gov/facts/oilimpacts.html. Accessed 2024-03-11.

37 Sordello, R., Ratel, O., Flamerie De Lachapelle, F. et al., 2020-08-11, Evidence of the impact of noise pollution on biodiversity: a systematic map. https://doi.org/10.1186/s13750-020-00202-y, Accessed 2024-12-12.

Biological Contamination:

The introduction of non-native species can disrupt local ecosystems. These invasive species can outcompete, predate upon, or bring diseases to native species, leading to reductions or extinctions of local biodiversity[38].

Pharmaceutical Pollution:

Wastewater treatment centres are not always effective at removing pharmaceuticals because the substances are small and can pass through the system. Medicines that end up in waterways, whether through improper disposal or as waste products from human use, can affect the health and behavior of aquatic organisms[39] and those organisms, including humans, that drink the water. A 2022 study suggests that over 40% of the world's rivers could contain harmful drugs[40].

Pollution affects almost every aspect of aquatic environments and the biodiversity within them, making pollution control and management a critical aspect of conserving water-related biodiversity.

Conclusion

Water is essential for supporting all forms of life, which keeps ecosystems balanced. Protecting and wisely managing water systems is important for promoting a variety of plant and animal life, strengthening the ability of ecosystems to cope with changes, and supporting healthy human communities. This variety of life makes ecosystems more resilient, allowing them to better handle changes like climate change and disasters. Protecting water is key to supporting life on Earth and shows how connected we are to nature and its well-being.

Call to Action

By adopting these actions, individuals and communities can play a significant role in preserving healthy water systems and promoting biodiversity

38 National Oceanic and Atmospheric Administration, 2019-04-02, What is an invasive species?. https://oceanservice.noaa.gov/facts/invasive.html. Accessed 2024-03-11.

39 Arnold, K.E., Brown, A.R., Ankley, G.T., & Sumpter, J.P. 2014-11-19, Medicating the environment: assessing risks of pharmaceuticals to wildlife and ecosystems. https://doi.org/10.1098/rstb.2013.0569. Accessed 2024-12-12.

40 Ashworth, J., 2022, Drug pollution is threatening the water quality of the world's rivers. https://www.nhm.ac.uk/discover/news/2022/july/drug-pollution-threatening-water-quality- worlds-rivers.html. Accessed 2024-03-13.

1. **Use Water Wisely**:
   Install water-saving devices in your home and practice water conservation habits, such as fixing leaks promptly, using drought-resistant plants in your garden, and watering lawns and plants during the cooler parts of the day.
2. **Support Local Conservation Efforts**:
   Participate in or donate to local biodiversity projects, such as tree planting, wetland restoration, and community gardens. These efforts help to improve water quality and enhance biodiversity.
3. **Avoid Polluting**:
   Properly dispose of hazardous substances like paints, motor oil, and chemicals. Never pour these substances down the drain or onto the ground.
3. **Promote Native Planting**:
   Plant native species in your garden and community spaces. Native plants are better adapted to the local environment, require less water, and provide essential habitat for native wildlife.
4. **Minimize Use of Chemicals**:
   Reduce or eliminate the use of pesticides and fertilizers in gardening and landscaping. Consider the wise use of these chemicals to prevent them from running off into local waterways, harming water quality and aquatic life.
6. **Engage in Citizen Science**:
   Participate in local biodiversity and water quality monitoring projects. Data collected by community members can be invaluable for conservation efforts.
7. **Reduce Stormwater Runoff**:
   Implement rainwater harvesting, create rain gardens, and use permeable paving materials to reduce stormwater runoff and increase groundwater recharge.

Teaching Ideas

Discussion Questions

These questions intend to inspire critical thinking, empathy for the environment, and a deeper understanding of the interconnectedness of ecosystems.

What are the Main Causes of Biodiversity Loss?

Have students identify and discuss the major factors contributing to biodiversity loss, such as habitat destruction, climate change, pollution, invasive species, and

overexploitation of resources. This question can lead to discussions on how human activities influence these factors.

Can You Think of a Local Example of Biodiversity Loss? What Caused It?

This question personalizes the issue, prompting students to research and reflect on biodiversity loss in their own communities. It can lead to discussions about local conservation efforts and challenges.

How Does Biodiversity Loss Affect Human Societies?

Encourage students to explore the direct and indirect impacts of biodiversity loss on human societies, including food security, medicine, ecosystem services (like water purification and flood protection), and cultural impacts.

What Role Do Protected Areas Play in Biodiversity Conservation?

Ask students to discuss the role of national parks, wildlife reserves, and other protected areas in conserving biodiversity. This can lead to a debate on the balance between conservation and human needs for land and resources.

How Can Indigenous Knowledge Contribute to Biodiversity Conservation?

Encourage a discussion on the role of Indigenous Peoples in biodiversity conservation, including how their knowledge, practices, and relationship with the environment can teach broader society about sustainable living.

What are Some Solutions to Biodiversity Loss?

Have students brainstorm and evaluate different strategies to reduce or reverse biodiversity loss, including legal measures, conservation projects, sustainable resource management, and technological innovations.

How Can Individuals and Communities Contribute to Biodiversity Conservation?

Encourage students to think about actions they and their communities can take to support biodiversity, such as participating in or organizing local conservation projects, making sustainable lifestyle choices, and advocating for policies that protect the environment.

Should Economic Development be Prioritized Over Biodiversity Conservation?

This debate question invites students to discuss the trade-off between economic growth and environmental protection. It can lead to a nuanced conversation about sustainable development and finding a balance that supports both economic and ecological well-being.

What is the Role of Technology in Biodiversity Conservation?

Have students explore how modern technologies (like remote sensing, bioacoustics, and genetic engineering) are being used in biodiversity conservation, including their potential benefits and ethical considerations.

Interactive Activities

Interactive Web Quests

The Water-Biodiversity Nexus: Create an interactive map online highlighting various global water bodies and their significance to local biodiversity. Students can click on locations to learn about specific water-related ecosystems and the species they support

Role-Playing Simulations

Community Stakeholder Simulation: Students assume the roles of different community stakeholders (e.g., farmers, policymakers, local business owners, Indigenous peoples) in a role-playing game.

They debate and negotiate to implement nature-based solutions that balance economic development and biodiversity conservation.

Project-Based Learning

Local Biodiversity Audit: Students conduct a biodiversity audit of their school or community. They identify species, assess habitat quality, and propose actions to enhance local biodiversity, such as planting native plants or creating wildlife habitats.

Eutrophication

What is "eutrophication"?

Eutrophication is the increase in the concentration of nutrients, primarily nitrogen and phosphorus, in a water body [41]. These nutrients can trigger events in the water body such as excessive growth of organisms such as algae in events called "algal blooms". These blooms can produce toxins that are harmful to aquatic life and humans, reduce underwater light levels which reduces photosynthesis and creates dead zones where oxygen levels are too low to support aquatic life. In sum, these various effects can collapse the local ecosystem [42].

Beyond the effect on the aquatic ecosystem, eutrophication can threaten human health by contaminating drinking water supplies [43] and requiring more expensive treatments to make the water drinkable.

Eutrophication is a growing global problem. A 2009 report [44] for the World Resources Institute noted that in 1960, 10 coastal dead zones had been documented. By 2008, the number of coastal dead zones was 405. Climate change is expected to make the eutrophication problem worse [45].

What causes it?

Eutrophication can arise naturally over time. However, more typically, it is the result of a sudden increase in nutrients resulting from human activities such as poor

41 Encyclopaedia Brittanica, 2024, Eutrophication. https://www.britannica.com/science/eutrophication. Accessed 2024-02-28.

42 World Resources Institute, n.d., Eutrophication and Hypoxia. https://www.wri.org/initiatives/eutrophication-and-hypoxia/learn. Accessed 2024-02-29.

43 Government of Ontario, 2022, Blue-green algae. https://www.ontario.ca/page/blue-green-algae. Accessed 2024-02-28.

44 Selman, M. and Greenhalgh, S., 2008, Eutrophication: Policies, Actions, and Strategies to Address Nutrient Pollution. https://files.wri.org/d8/s3fs-public/pdf/eutrophication_policies_actions_and_strategies.pdf. Accessed 2024-02-29.

45 Sinha, E., Michalak, A.M. and Balaji, V., 2017, Eutrophication will increase during the 21st century as a result of precipitation changes. https://www.science.org/doi/10.1126/science.aan2409. Accessed 2024-02-29.

sewage management, industrialised forestry [46], urban run-off or agricultural run-off. Agricultural run-off is typically in the form of chemically manufactured fertiliser or untreated sewage. This results in water bodies receiving more nutrients than they can normally process. Natural eutrophication is a slow and gradual process, but human activities can accelerate it and this results in the explosive growth of algae [47].

Agriculture

Poor water use practices, including inefficient irrigation and over-extraction of water, can worsen eutrophication. Agriculture, which accounts for about 70% of global freshwater use [48], plays a significant role. In Africa and Asia, it is estimated that agriculture accounts for 85-90% of freshwater use [49]. In stark contrast, Canada's agricultural water use is around 11% [50].

Inefficient irrigation methods result in runoff, which carries fertilizers and pesticides into nearby water bodies [51]. Over-extraction of water for agricultural, industrial, and domestic use lowers water levels, concentrating nutrients and pollutants, making water bodies more susceptible to eutrophication.

Urban communities

Urbanization often contributes to poor water practices. Impermeable surfaces such as roads, sidewalks and parking lots in urban areas increase runoff, which carries nutrients (and pollutants) from urban landscapes into water bodies. The lack of adequate sewage treatment facilities in many communities means that untreated

46 Bonsdorf, E., 2021, Eutrophication: Early warning signals, ecosystem-level and societal responses, and ways forward. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7982367/. Accessed 2024-02-29.

47 Government of Ontario, 2022, Blue-green algae. https://www.ontario.ca/page/blue-green-algae. Accessed 2024-02-28.

48 World Bank, 2022, Water in Agriculture. https://www.worldbank.org/en/topic/water-in-agriculture. Accessed 2024-02-28.

49 Government of Canada, 2020, Agriculture and water quality. https://agriculture.canada.ca/en/environment/managing-water-sustainably/agriculture-and-water-quality. Accessed 2024-02-28.

50 Statistics Canada, 2024, Canadian System of Environmental–Economic Accounts: Water use, 2021. https://www150.statcan.gc.ca/n1/daily-quotidien/240711/dq240711a-eng.htm. Accessed 2024-09-19.

51 Government of Canada, 2020, Agriculture and water quality. https://agriculture.canada.ca/en/environment/managing-water-sustainably/agriculture-and-water-quality. Accessed 2024-02-28.

or partially treated wastewater is often discharged into rivers and lakes, further enriching them with nutrients.

Community practices also significantly impact the health of water bodies. The use of human-made fertilizers and pesticides in residential areas contributes to nutrient runoff. Practices such as improper disposal of waste including manure and compost, and the lack of green infrastructure [52], such as rain gardens and permeable pavements, to absorb runoff exacerbate the problem.

Also, people living near water bodies often engage in activities that can directly contribute to eutrophication. These include recreational boating and fishing, which can increase erosion and runoff, and waterfront development, which often leads to shoreline habitat destruction and increased pollution.

What can be done to reduce eutrophication?

Eutrophication is a complex issue with many possible causes, both natural and human-induced. Consequently, dealing with it and managing its harmful effects requires action on many fronts.

Adopting sustainable agricultural practices

Sustainable agriculture practices, such as precision farming [53] or regenerative agriculture , can significantly reduce runoff by ensuring that fertilizers and water are used efficiently. Precision farming is, essentially, the intense use of data about factors such as soil moisture, fertiliser uptake, soil fertility and so on to allow for optimised application of water, fertilisers, and other inputs only where, when and in the amount needed. An example of this approach in practice in Canada is the "4R Nutrient Stewardship" program [54].

52 Green Infrastructure Ontario Coalition, n.d., Green Infrastructure: Overview. https://greeninfrastructureontario.org/what-is-green-infrastructure/. Accessed 2024-02-28.

53 MacIntosh, M., n.d., Precision Farming: What is it? https://canadianfoodfocus.org/on-the-farm/precision-farming-what-is-it/. Accessed 2024-02-29.

54 Fertilizer Canada, n.d., Stewardship. https://fertilizercanada.ca/our-focus/stewardship/. Accessed 2024-09-19.

Cover cropping [55] and buffer zones , especially near riparian areas, can also prevent soil erosion and reduce nutrient runoff into waterways. Agricultural runoff management requires a careful analysis of water and pollutant flows and may require the creation of treatments such as vegetation filter strips or constructed wetlands [56] (pp.79-83).

More-informed community practices

Communities can play a vital role by adopting green infrastructure solutions that reduce runoff and by promoting the appropriate use of organic fertilizers (i.e. manure and compost) and pesticides. Enhancing wastewater treatment processes to remove nutrients before they are discharged into water bodies is crucial. As is so often noted, prevention is better than cure.

Enhancing wastewater treatment

Wastewater treatment facilities can often be installed or upgraded to enable the removal of nutrients from the waste stream before the water reaches water bodies [57]. For communities relying on septic systems, promoting regular maintenance to prevent leaks and overflows is vital in reducing nutrient seepage into the groundwater and nearby water bodies. In Canada in 2017, it is estimated that 270 million cubic metres of untreated wastewater was released into the environment [58]. While a large volume, it should be noted that the untreated volume is only 4.4% of the total wastewater volume produced in Canada.

55 California State University Chico, n.d., Cover Cropping. https://www.csuchico.edu/regenerativeagriculture/ra101-section/cover-crop-biomass.shtml. Accessed 2024-02-29.

56 Alberta Agriculture and Rural Development, 2010, Beneficial Management Practice: Environmental Manual for Livestock Producers in Alberta. https://open.alberta.ca/publications/4851540. Accessed 2024-02-29.

57 Preisner, M., Neverova-Dziopak, E., and Kowalewski, Z., 2021, Mitigation of eutrophication caused by wastewater discharge: A simulation-based approach. https://link.springer.com/article/10.1007/s13280-020-01346-4. Accessed 2024-02-29.

58 Statistics Canada, 2019, Municipal wastewater systems in Canada, 2013 to 2017. https://www150.statcan.gc.ca/n1/daily-quotidien/190625/dq190625c-eng.htm. Accessed 2024-06-25.

Implementing green infrastructure

The use of green infrastructure [59] such as rain gardens, bioswales, green roofs in residential and commercial areas absorbs rainwater runoff and helps to filter out nutrients before they enter waterways. Similarly, the use of permeable pavements [60] enables water to infiltrate the ground, reducing runoff and filtering pollutants. An important possible benefit of the infiltration is that it may help in recharging aquifers and retaining water for future use.

Social and educational campaigns

Communities play a crucial role in combating eutrophication in lakes and rivers. By adopting sustainable practices and fostering environmental stewardship, communities can significantly reduce the influx of nutrients into water bodies. By implementing the following strategies, communities can significantly reduce the nutrient loads entering their lakes and rivers, thus mitigating eutrophication and its adverse effects. Active community involvement, coupled with strong policies and sustainable practices, can lead to healthier water bodies and ecosystems.

Community education and engagement campaigns

By raising awareness of the issue, public awareness campaigns can educate community members about the causes, dangers and effects of eutrophication and how the community can contribute to its reduction. Similarly, "citizen science" programs (e.g. Water Rangers [61], or Our Living Waters [62] – a partner charity) and the Trout Unlimited Canada Yellow Fish Road program [63] can engage community members in monitoring water quality in local lakes and rivers. This can increase awareness and provide valuable data for managing eutrophication.

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59 Capital Regional District, n.d., Green Stormwater Infrastructure. https://www.crd.bc.ca/education/stormwater-wastewater-septic/green-stormwater-infrastructure. Accessed 2024-02-29.

60 Capital Regional District, n.d., Permeable paving. https://www.crd.bc.ca/education/stormwater-wastewater-septic/green-stormwater-infrastructure/permeable-paving. Accessed 2024-06-25.

61 Water Rangers. https://www.waterrangers.ca/. Accessed 2024-02-29.

62 Our Living Waters. https://www.ourlivingwaters.ca/. Accessed 2024-02-29.

63 Trout Unlimited Canada, n.d., Yellow Fish Road. https://tucanada.org/education-training/yellow-fish-road/. Accessed 2024-06-25.

Policy and regulation

Communities can advocate for stronger regional, provincial, and national regulations on nutrient pollution, including limits on the use of fertilizers and pesticides in agriculture. It may also be possible to create fiscal and economic incentives (e.g. taxes, subsidies) which incentivise nutrient reducing activities.

At a more local level, communities can implement bylaws which:

- Modify zoning and land-use planning to protect waterways from excessive nutrient runoff and promote sustainable development.
- Guide the use of fertilisers and pesticides within urban areas.

Restoration projects

Communities can support projects to restore wetlands and riparian buffer zones. Landowners can work with organisations such as Ducks Unlimited, Cows & Fish and ALUS in restoring wetlands on their land.

Restored riparian buffers along waterways are critical in intercepting surface runoff and providing habitat and biodiversity. Wetlands act as natural filters, trapping nutrients and sediments before they reach larger bodies of water (e.g. Vancouver's constructed wetland on Lost Lagoon [64]). And, very helpfully, such areas can help with flood mitigation [65].

Adopting sustainable landscaping and gardening practices

Communities can encourage the appropriate use of fertilisers through education campaigns focussed on proper amounts and timing of fertiliser use. Promoting the use of native plants in landscaping will reduce the need for fertilisers as the plants are adapted to local conditions. Such plants may also need less water and so reduce the risk of runoff.

64 Kerr Wood Leidal, n.d., Stanley Park Stormwater Treatment Wetland. https://www.kwl.ca/project/stanley-park-stormwater-treatment-wetland/. Accessed 2024-02-29.

65 Opperman, J. and Galloway, G.E., 2022, Nature-based solutions for managing rising flood risk and delivering multiple benefits. https://www.sciencedirect.com/science/article/pii/S2590332222002135. Accessed 2024-02-29.

Conclusion

Active community involvement, coupled with strong policies and sustainable practices, can lead to healthier water bodies and ecosystems.

By supporting and implementing the strategies identified above and others that may be more appropriate for your particular areas and issues, you can significantly contribute to the reduction of nutrient loads entering your lakes and rivers. By doing so, you will be helping to mitigate eutrophication and its adverse effects.

Call to Action

Become aware:

- Do any of the water bodies in your area have eutrophication?
- Do you know why it is happening?
- Is anything being done to slow or stop it?

Teaching Ideas

Group activities

1. Share or read stories or books that feature the concept of eutrophication and its effects on aquatic ecosystems, making it relatable and engaging.
2. Show age-appropriate videos or animations that explain eutrophication and its consequences in an engaging and easy-to-understand way.
3. Facilitate discussions about the sources of nutrient pollution, such as agricultural runoff and household waste, and encourage children to brainstorm ways to reduce it.

Science experiments

1. Create small-scale models of a lake or pond using a container, water, and materials like sand and plants. If time permits, add fertilizer to demonstrate how nutrient overload leads to algae growth and eutrophication. Perhaps compare between models demonstrating different effects. Simpler variation: use jars of water and add varying amounts of fertilizer to observe algae growth over time.
2. Start a garden project where children can learn about the importance of using fertilizers responsibly and the impact of excess nutrients on the environment.

Art & multimedia projects

1. Explain what eutrophication is, using age-appropriate language and visual aids such as diagrams, illustrations or collages.
2. Encourage children to create posters or drawings depicting healthy and eutrophic water bodies, helping them visualize the differences and understand the importance of preventing nutrient pollution.

Field Trips

Arrange visits to local water bodies or nature centres where eutrophication can be observed. Guides can explain the process and its impact on the ecosystem.

Forests

Forests are essential in maintaining the balance of the Earth's atmosphere, water cycle, and climate. They provide habitats for countless organisms, support the livelihoods of billions of humans, and contribute to soil fertility. Forests provide key resources for many industries, such as lumber, paper manufacturing, pharmaceuticals, tourism, and food. They offer recreational areas, spiritual and cultural significance, and are vital for research and education [66]. In Canada, forests cover 3.6 million square kilometres of land, which is about 40% of the country [67].

Different types of forests are defined based on their characteristics such as tree density, geographical location, climate, height, land use, and ecological function. There are three types of forests based on latitude: boreal, temperate and tropical [68].

As seen in a forest map of Canada, the boreal forest dominates northern regions [69].

Why Bother Learning About Forests?

Learning about forests helps people understand how their local forests have been managed in the past, and advocate for better ways to take care of them. This can help reduce deforestation by raising people's awareness of the consequences of forest loss, while promoting the importance of restoration and conservation of these important ecosystems. This, in turn, helps our waters.

Elements of Forests

Forests are complex ecosystems that include many elements working together to create a unique and diverse environment. They are made up of abiotic (non-living) and biotic (living) features. Let's break down the key elements of forests:

66 Doyle, H., 2024-02-07, Sacred forests: Where conservation meets the spiritual. https://theclimatenews.co.uk/sacred-forests-where-conservation-meets-the-spiritual. Accessed 2024-12-09.

67 Wastesicoot, R., 2022-06-05, One Tree at a time: Canada's forests. https://www.natureconservancy.ca/en/blog/archive/one-tree-at-a-time-canadas.html. Accessed 2024-12-09.

68 Nordseth, A., 2026-06-01, Types of forests: Definitions, examples, and importance. https://www.treehugger.com/types-of-forests-definitions-examples-5180645. Accessed 2024-12-09.

69 Wastesicoot, R., 2022-06-05, One Tree at a time: Canada's forests. https://www.natureconservancy.ca/en/blog/archive/one-tree-at-a-time-canadas.html. Accessed 2024-12-09.

Biotic elements of a forest [70]

Trees	Ferns	Fungi	Reptiles
Shrubs	Mosses	Mammals	Insects
Flowering plants	Lichens	Birds	Microbes

Abiotic elements of a forest [71]

Sunlight	Rocks
Soil	Water
Minerals	

Water, an abiotic element, is essential to forests, serving as a critical component in the symbiotic relationship fuelling the forest ecosystem. At the core of this relationship is evapotranspiration, where water is recycled back into the atmosphere from forests through a combination of evaporation from soil and plant surfaces and transpiration from plant foliage [72].

Between 20% to 90% of precipitation that falls on forests is returned to the atmosphere through evapotranspiration, demonstrating forests' role in the water cycle and regulating atmospheric moisture [73]. The role of water in forest ecosystems extends beyond evapotranspiration; water that doesn't vaporize can become runoff, adding to streams and lakes, while the remainder sinks into the ground and recharges groundwater reserves.

Forests act as nature's water purifiers. As water travels through forested landscapes, it is naturally filtered as the forest soils, microbes, and plants absorb pollutants such as mercury and pesticides [74]. This natural filtration process enhances water quality.

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70 Spirko, J., 2019-03-02, List of biotic and abiotic factors in a forest ecosystem. https://sciencing.com/list-abiotic-factors-forest-ecosystem-8092398.html. Accessed 2024-03-08.

71 Spirko, J., 2019-03-02, List of biotic and abiotic factors in a forest ecosystem. https://sciencing.com/list-abiotic-factors-forest-ecosystem-8092398.html. Accessed 2024-03-08.

72 U.S. Geological Survey, 2018-06-12, Evapotranspiration and the water cycle completed. Evapotranspiration and the Water Cycle. https://www.usgs.gov/special-topics/water-science-school/science/evapotranspiration-and-water-cycle. Accessed 2024-12-09.

73 Natural Resources Canada, 2021-02-16, Water. https://natural-resources.canada.ca/our-natural-resources/forests/sustainable-forest-management/conservation-and-protection-canadas-forests/water/13207. Accessed 2024-12-09.

74 Natural Resources Canada, 2021-02-16, Water. https://natural-resources.canada.ca/our-natural-resources/forests/sustainable-forest-management/conservation-and-protection-canadas-forests/water/13207. Accessed 2024-12-09.

In addition, forests help control when and how much water flows into water bodies; soil erosion is reduced when water moves slowly through and across the land [75]. This regulation is important for keeping stable water quality and supply for nearby communities.

Deforestation 101

What is Deforestation?

Deforestation is the deliberate clearing of trees and forest areas without the intention of replanting. Humans have been cutting down forests throughout history to create space for farming and raising animals, to obtain wood for heating, and building. This has changed the way places around the world look. For example, 2,000 years ago, 80% of Western Europe was covered in trees, but now only 34% is [76] forested. In North America, about half of the eastern forests were chopped down between the 1600s and the 1870s to use the wood for building and for farming. China has also seen a big decrease in its forests over 4,000 years, with just over 20% remaining forested today [77]. Currently, the most global deforestation is happening in tropical rainforests. As new roads are built in rainforests, they make the resources in these once-isolated regions easier to access which encourages more roads and more resource harvesting.

Recent studies identify that sea-level rise and increased saltwater flooding from storms and high tides are reasons for deforestation. These factors cause the groundwater level to rise, resulting in saturated soils in low coastal forest areas. This waterlogged condition deprives tree roots of oxygen, stressing the trees, preventing new growth, and eventually leading to the death of the tree [78]. In deforested areas, trees are unable to reseed and regrow.

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75 Lyons, K., & Gartner, T., 2017-03-21, 3 surprising ways water depends on healthy forests. https://www.wri.org/insights/3-surprising-ways-water-depends-healthy-forests. Accessed 2024-03-08.

76 National Geographic, n.d., Deforestation. https://education.nationalgeographic.org/resource/deforestation/. Accessed 2024-03-08.

77 National Geographic, n.d., Deforestation. https://education.nationalgeographic.org/resource/deforestation/. Accessed 2024-03-08.

78 USDA Climate Hubs, n.d., Climate Change Impacts to Coastal Forests. https://www.climatehubs.usda.gov/hubs/northeast/topic/climate-change-impacts-coastal-forests. Accessed 2024-12-09.

How Does Deforestation Affect the Environment?

Deforestation impacts water resources and the hydrological cycle in both the present and long-term future, changing ecosystems and water availability and quality across landscapes. Understanding how deforestation affects water involves considering several key aspects:

Altered Hydrological Cycle

Forests absorb rainfall and release water vapor back into the atmosphere through transpiration. This process contributes to the formation of clouds and precipitation. Deforestation disrupts this cycle, leading to reduced rainfall in some areas, which can worsen conditions of drought [79]. Additionally, the absence of trees means that less water is absorbed by the forest floor, altering the flow of groundwater and surface water systems [80].

Increased Runoff and Reduced Water Quality

When trees are cut down, there is no canopy or roots to absorb rainfall, which can lead to more water running off the land instead of slowly being absorbed by plants or soil. This is called surface runoff, and can carry sediments, nutrients from fertilizers or sewage such as phosphates or ammonia, pesticides, and other pollutants into rivers, lakes, and streams, significantly lowering the water quality [81]. Without trees and other plants, water isn't filtered as well, and this can cause too many nutrients and pollutants to build up in water bodies. Ammonia and phosphates are naturally occurring, but when there is too much added from external sources, that can cause algae blooms, which can disrupt a healthy aquatic ecosystem, throwing it off balance. This is called eutrophication; it depletes oxygen in the water, blocks sunlight, and the algae can be toxic to some animals and plants. Eutrophication can completely change an aquatic ecosystem.

79 Dhaliwal, B., 2023-02-08, How deforestation affects the water cycle. https://www.earthday.org/how-deforestation-affects-the-water-cycle/. Accessed 2024-12-09.

80 Sunshine Coast Conservation Association, n.d., Impacts to our Watersheds. https://thescca.ca/learn-discover/watersheds-and-our-water-supply/impacts-to-our-watersheds/. Accessed 2024-12-09.

81 Boyle, R., 2024-02-22, The devastating impact of deforestation on watershed management. https://www.emission-index.com/deforestation/watershed-management. Accessed 2024-03-08.

Changes in Water Availability

Forests help control the amount of water run-off in watersheds by soaking up rain and snowmelt and slowly releasing it into rivers and groundwater, ensuring a steady supply of water. Deforestation can lead to more erratic water availability, with periods of flood followed by droughts, affecting ecosystems and communities relying on consistent water sources for drinking, agriculture, and industry [82].

Soil Erosion and Sedimentation

Tree roots and forest floor hold soil in place, preventing erosion. When forests are cleared, the exposed soil is more susceptible to being washed away by rainwater. This erosion leads to the loss of fertile topsoil and contributes to the sedimentation of rivers and streams, affecting aquatic habitats and increasing the cost of water treatment for human use [83].

Impact on Climate and Precipitation Patterns

Deforestation contributes to climate change by releasing greenhouse gases such as stored carbon dioxide (CO_2) into the atmosphere when trees are burned or decay. With an increase in greenhouse gases in the atmosphere, the world weather patterns change, resulting in changes to when, how and how much water is arriving in an area. Forest loss leads to less evapotranspiration, which can decrease local rainfall and lead to drier conditions [84].

Temperature Regulation

Forests have a cooling effect on the environment by providing shade and releasing moisture into the air through transpiration. When trees are removed, the temperatures in those areas can rise, which affects how water evaporates and

82 Marsh, J., 2023-01-04, Deforestation and droughts tend to worsen one another. https://www.sustainability-times.com/environmental-protection/deforestation-and-droughts-tend-to-worsen-one-another/. Accessed 2024-03-08.

83 WWF, n.d., What is erosion? effects of soil erosion and land degradation. https://www.worldwildlife.org/threats/soil-erosion-and-degradation. Accessed 2024-03-08.

84 Guardian News and Media. (2023, March 1). Scientists prove clear link between deforestation and local drop in rainfall. The Guardian. https://www.theguardian.com/environment/2023/mar/01/scientists-prove-clear-correlation-between-deforestation-and-rainfall-levels. Accessed 2024-03-08.

reduces the amount of water in water bodies [85]. Higher temperatures can disrupt the temperature of nearby water, which can harm fish and other aquatic life.

Deforestation's Impact on Bio Swales and Urban Forests

Deforestation can significantly impact bioswales, which are landscape elements designed to concentrate and convey stormwater runoff while removing debris and pollution [86]. Bioswales are important for managing water flow in both urban and natural settings, improving water quality, and supporting local ecosystems.

Urban forests provide recreational spaces for residents and enhance mental and physical well-being. They also improve the aesthetic value of urban areas, making cities more liveable and attractive [87]. Deforestation deprives urban dwellers of these benefits, potentially leading to decreased quality of life and lower property values.

Canada's Forest Types

Canada's diverse landscape is home to a variety of forests, each unique to the specific climates across the country. From the coastal temperate rainforests of British Columbia to the cold-resilient boreal forests stretching across the north, and the mixed woods of the eastern provinces, Canada's forests are varied. This diversity underscores the ecological richness of Canada's natural heritage.

There are eight types of forests found in Canada:

1. Boreal Forest

The boreal zone can be found between 50 and 60 degrees latitude, and makes up 75% of forests in Canada [88].

85 Using Trees and Vegetation to Reduce Heat Islands. (2023, October 31). *Using Trees and Vegetation to Reduce Heat Islands*. EPA. https://www.epa.gov/heatislands/using-trees-and-vegetation-reduce-heat-islands. Accessed 2024-03-08.

86 CRD, 2013-11-10, Bioswales. https://www.crd.bc.ca/education/stormwater-wastewater-septic/green-stormwater-infrastructure/bioswales . Accessed 2024-03-08.

87 Chiesura, A., 2004, The role of Urban Parks for the sustainable city. https://doi.org/10.1016/j.landurbplan.2003.08.003. Accessed 2024-03-08.

88 Wastesicoot, R., 2022-06-05, One Tree at a time: Canada's forests. https://www.natureconservancy.ca/en/blog/archive/one-tree-at-a-time-canadas.html. Accessed 2024-12-09.

2. Carolinian Forest

In southwestern Ontario, the "Carolinian" forests are the smallest forest region in Canada and cover just 1% of Canada's land area. While they contain the greatest number of native tree species of any region [89], they are also home to about one-third of the country's endangered species [90]. Increased industrialization, urban expansion, and agricultural practices have put immense pressures on the Carolinian forest, leading to the decline of many species.

3. Coastal Forest

Coastal temperate forests along Canada's West Coast originally made up less than 0.2% of the Earth's surface, and more than half have been lost [91].

4. Columbia Forest

The Columbia Forest region is found in southeastern British Columbia's wet belt, between the central plateau and the Rocky Mountains. It is located at lower elevations in river valleys, mixed with subalpine forests. While this region is less wet than the coast, it gets plenty of moisture from snowmelt, supporting the forest. Many of the same types of trees can be found in both this region and the coast, though the Columbia Forest has a slightly smaller variety of species [92].

5. Great Lakes-St. Lawrence Forest

The Great Lakes–St. Lawrence Forest region extends from southeastern Manitoba to Quebec's Gaspé Peninsula, making it the second largest forest in Canada. This forest serves as a transitional zone, bridging the gap between the deciduous Carolinian forests in the south and the predominantly coniferous Boreal Forest [93].

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89 Nature Conservancy of Canada, n.d., Carolinian forest. https://www.natureconservancy.ca/en/what-we-do/resource-centre/forests-101/carolinian-forest.html. Accessed 2024-12-09.

90 Nordseth, A., 2026-06-01, Types of forests: Definitions, examples, and importance. https://www.treehugger.com/types-of-forests-definitions-examples-5180645. Accessed 2024-12-09.

91 Wastesicoot, R., 2022-06-05, One Tree at a time: Canada's forests. https://www.natureconservancy.ca/en/blog/archive/one-tree-at-a-time-canadas.html. Accessed 2024-12-09.

92 Nature Conservancy Canada, n.d., Columbia Forest. https://www.natureconservancy.ca/en/what-we-do/resource-centre/forests-101/columbia-forest.html. Accessed 2024-03-08.

93 Nature Conservancy Canada, n.d., Great Lakes- St. Lawrence Forest. https://www.natureconservancy.ca/en/what-we-do/resource-centre/forests-101/columbia-forest.html. Accessed 2024-03-08.

6. Montane Forest

The montane forests located in central British Columbia and western Alberta are characterized by their dry conditions. The tree species in these forests are heavily influenced by geographical elevation; some species will grow low in valleys or flatlands or along rivers, while others only grow higher up on mountain sides. Sunny sides of valleys will have different species than shady sides. Fire has been an important natural process here as well; some trees are highly adapted to regrow quickly after a forest fire [94].

7. Subalpine Forest

Spanning British Columbia and Alberta, the subalpine forest region is known for cooler temperatures, brief growing season, and extended winters. Avalanches significantly contribute to the diversity and dynamic changes within this forest area [95].

8. Acadian Forest

The Acadian Forest, the main forest type in Nova Scotia, Prince Edward Island, and New Brunswick, is exclusive to these areas. It is home to over 30 native tree species. Today, less than 1% of the original old-growth Acadian Forest still exists, placing it among the most uncommon forest types in North America [96].

Threats to Canada's Forests

Canada's vast landscapes and rich natural resources, including its extensive forests and freshwater systems, are under increasing pressure from various environmental challenges and human activities.

94 Nature Conservancy Canada, n.d., *Montane Forest*. https://www.natureconservancy.ca/en/what-we-do/resource-centre/forests-101/montane-forest.html. Accessed 2024-03-08.

95 Nature Conservancy Canada, n.d., Subalpine Forest. https://www.natureconservancy.ca/en/what-we-do/resource-centre/forests-101/columbia-forest.html. Accessed 2024-03-08.

96 Nature Conservancy Canada, n.d., Acadian Forest. https://www.natureconservancy.ca/en/what-we-do/resource-centre/forests-101/columbia-forest.html. Accessed 2024-03-08.

The Boreal forests face a significant challenge from climate change, with nearly 80% of these forests situated above permafrost (a soil layer that is frozen year-round) [97]. As global temperatures rise, this permafrost thaws, turning the ground beneath the forests into soft terrain. As a result, trees can be destabilized, leaning, falling over, or even die because their roots are not firmly anchored in the ground. When a tree dies, it releases carbon back into the atmosphere as it decomposes, becoming a source of atmospheric carbon. Experts at the International Boreal Forest Research Association highlight the role of conserving boreal forests in mitigating the effects of climate change, emphasizing their importance in the broader environmental context [98].

Some Canada-specific examples of loss of water-related forest conservation concerns highlight the intricate balance between natural ecosystems and human activities:

Alberta Oil Sands Development

One of the most prominent examples of environmental concern related to water and forests in Canada is the development of the Alberta oil sands. Oil sand is just that - oil mixed with sand - and it is often called bitumen. Extracting bitumen from the ground, moving it, and separating the oil from the sand requires a significant amount of water, and the processes involved can lead to large amounts of toxic water or "tailings" [99]. Because bitumen is found in large deposits under the boreal forest, large swaths of the forest have to be removed in order to mine the oilsands. This has not only reduced forest cover and wildlife habitat, but also affected the quality and quantity of water in the region due to industrial emissions and water withdrawal from rivers and groundwater [100]. Because the Athabasca river flows past many of the oil sands mines, there is concern about the health of the Peace-

97 Carpino, O. A., Berg, A. A., Quinton, W. L., & Adams, J. R., 2018, Climate change and permafrost thaw-induced boreal forest loss in northwestern Canada. https://doi.org/10.1088/1748-9326/aad74e. Accessed 2024-03-08.

98 Carpino, Olivia, et al., 2018, Climate change and permafrost thaw-induced boreal forest loss in northwestern Canada. https://doi.org/10.1088/1748-9326/aad74e. Accessed 2024-03-08.

99 Weisbrod, K. (2022, January 24). Canada's Tar Sands: Destruction so vast and deep it challenges the existence of land and people. Inside Climate News. https://insideclimatenews.org/news/21112021/tar-sands-canada-oil/. Accessed 2024-03-08.

100 SubjectToClimate, n.d, How Does Deforestation Affect the Water Cycle? https://subjecttoclimate.org/teacher-guides/how-does-deforestation-affect-the-water-cycle. Accessed 2024-12-09.

Athabasca delta ecosystem as the water eventually pours into the Arctic ocean. The consequences of oil sands extraction is a matter of significant scientific and social debate.

British Columbia's Mountain Pine Beetle Epidemic

British Columbia and, more recently, Alberta, has faced a massive outbreak of the mountain pine beetle, which has killed millions of acres of pine trees across the provinces. The beetle larvae are killed off by winter temperatures in the -25°C to -40°C range at different times in the late-fall to early-spring period [101]. However, the warmer temperatures brought by climate change has allowed the infestations to increase and has led to a significant loss of forest cover [102]. The resulting deforestation affects watershed stability, water quality, and the region's ability to manage water resources effectively, contributing to increased runoff and sedimentation in water bodies. The dead trees also raise the risk of wildfires.

Logging Practices in the Boreal Forest

Canada's boreal forest, one of the largest intact forest ecosystems on the planet, faces threats from industrial logging practices [103]. These practices often lead to forest degradation, which disrupts the natural water cycle, reduces biodiversity, and affects water quality in nearby lakes, rivers, and streams. The loss of forested areas compromises the ecosystem's ability to filter water, exacerbate flooding, and regulate climate.

Wildfires and Water Resources

The number and strength of wildfires in Canada have been increasing, a trend that is partly due to climate change. These fires not only result in immediate loss of forest cover but they also have long-term effects on watershed health and water

101 Government of British Columbia, n.d., Biology of the Mountain Pine Beetle. biology_of_the_mountain_pine_beetle.pdf. Accessed 2024-12-09.

102 Government of British Columbia, 2024, Mountain Pine beetle. https://www2.gov.bc.ca/gov/content/industry/forestry/managing-our-forest-resources/forest-health/forest-pests/bark-beetles/mountain-pine-beetle. Accessed 2024-12-09.

103 Montgomery E., Herdman S. (2022, September 27). Threatened by logging, the Boreal Forest Needs Our Help. Environment America. https://environmentamerica.org/articles/threatened-by-logging-the-boreal-forest-needs-our-help. Accessed 2024-12-09.

quality [104]. After a wildfire, the loss of plants leads to more surface-water runoff, increased soil erosion, and a higher risk of flooding. This can harm the availability and quality of water for communities, agriculture, and wildlife.

Communities' Role in Reducing Deforestation

How can communities contribute to reducing water-related concerns in the context of deforestation?

Through collective action, education, and sustainable practices, local communities can significantly impact the preservation of forests and water resources. Here are several ways in which communities can contribute:

Participating in Reforestation Projects

Communities can organize or participate in reforestation projects to restore degraded forest lands. Planting native tree species helps to rebuild ecosystems, improve soil health, enhance water absorption into the ground, reducing runoff and erosion [105]. Reforestation also restores the natural water cycle, increasing the resilience of forests to fires and pests.

Adopting Sustainable Agriculture Practices

Agricultural activities are a significant driver of deforestation, especially when they involve slash-and-burn techniques or the conversion of forests into farmland. Communities can adopt sustainable agriculture practices such as agroforestry, which integrates trees and shrubs into agricultural landscapes [106]. This practice not only reduces the need for deforestation but also helps in improving soil quality and enhancing biodiversity.

104 Environmental Protection Agency, 2019-08-13, Wildfires: How Do They Affect Our Water Supplies? https://www.epa.gov/sciencematters/wildfires-how-do-they-affect-our-water-supplies. Accessed 2024-03-08.

105 Heeman's, n.d., The benefits of planting native trees. https://www.heeman.ca/garden-guides/native-trees/. Accessed 2024-12-09.

106 Soil Association, n.d., What is agroforestry? https://www.soilassociation.org/causes-campaigns/agroforestry/what-is-agroforestry/. Accessed 2024-12-09.

Supporting Sustainable Forest Management

Communities can support sustainable forest management practices that aim to balance ecological, social, and economic objectives. This includes advocating for and participating in the sustainable harvesting of timber, non-timber forest products, and wildlife. By supporting sustainable forest management, communities help ensure that forest resources are used responsibly, while maintaining their ability to regulate water cycles and quality.

Reducing Consumption and Waste

Communities can contribute to reducing deforestation by minimizing their consumption of products that lead to forest degradation, such as unsustainable palm oil, paper, and wood [107]. Promoting recycling, responsible purchasing, and the use of eco-friendly materials can lessen the pressure to harvest from forests.

Teaching Ideas

Discussion Questions

How does deforestation impact the hydrological cycle?

> This question prompts students to think about the role of forests in the hydrological cycle, including their impact on rainfall patterns, groundwater recharge, and the regulation of surface water flow.

What are the consequences of deforestation for aquatic ecosystems?

> Discuss the effects of deforestation on rivers, lakes, and wetlands, focusing on biodiversity loss, habitat destruction, and changes in water chemistry.

How does deforestation contribute to climate change, and what implications does this have for water resources?

> Explore the link between deforestation, greenhouse gas emissions, climate change, and discuss how altered climate patterns can affect water availability and quality.

107 WWF, n.d., Deforestation and forest degradation. https://www.worldwildlife.org/threats/deforestation-and-forest-degradation . Accessed 2024-12-09.

What are some examples of deforestation affecting water supply and quality in specific regions or communities?

Ask students to research and share case studies where deforestation has led to changes in water supply, quality, or access, particularly in vulnerable or Indigenous communities.

What are the ethical considerations in managing forests and water resources in a way that respects both the environment and human needs?

Prompt students to reflect on the ethical dilemmas involved in balancing conservation efforts with economic development and the needs of local communities.

How do global trends in deforestation affect international water security and cooperation?

Discuss how deforestation in one region can have ripple effects on water resources in other areas, potentially leading to conflicts over water or necessitating international cooperation to address shared challenges.

Activities

Role-Playing Game: The Deforestation Dilemma

Students assume the roles of various stakeholders affected by deforestation (e.g., farmers, government officials, Indigenous Peoples, conservationists). Through negotiation and debate, they must negotiate a sustainable land management plan that balances economic needs with the conservation of forests and protection of water resources.

Community Action Project: Tree Planting Initiative

Organize a tree planting day where students implement a reforestation project in their community or school grounds. This activity can be extended to include water conservation efforts, such as creating rain gardens or installing rain barrels, to emphasize the link between healthy forests and water resources.

Interactive Mapping of Global Deforestation

Using GIS (Geographic Information System) software or online platforms, students create interactive maps that track deforestation hotspots around the world and their proximity to critical water resources. This project encourages students to analyse spatial data and understand the global scale of deforestation impacts.

Debate Club: Forests and Water Rights

Host a debate on issues related to deforestation and water rights. Topics could include the rights of Indigenous Peoples to their ancestral forests, the responsibilities of corporations in water-stressed regions, or the role of

international agreements in protecting forests and water. This encourages critical thinking and public speaking skills.

Water and Forest Conservation Awareness Campaign

Students design and implement an awareness campaign aimed at educating their school and local community about the importance of forests in maintaining healthy water cycles. The campaign could include posters, social media content, interactive workshops, and community presentations.

Documentary: Forests and Water

Organize a viewing of documentaries that explore the relationship between forests and water resources. Follow up the viewing with a guided discussion or Q&A session with experts in forestry, water management, or environmental conservation to deepen students' understanding and engagement with the topic.

Groundwater

Groundwater is a vital natural resource which, although mostly out of sight, sustains life on Earth. Amongst other things, groundwater provides drinking water, and is widely used by agriculture and industry. In fact, in Canada, about 30% of the population depends on groundwater for domestic use [108]. When looking at the world's population, that number rises to an estimated 50% [109].

However, extracting too much water from the ground can lead to serious consequences for both communities and ecosystems.

In this article, we explore some of the challenges which surround groundwater use and will look at ways to manage those complexities.

What is groundwater?

First of all, let's define groundwater. For the purposes of this discussion, groundwater is subsurface (i.e. underground) water which originates from rainfall or snowmelt that penetrates the layer of soil just below the surface. For us to be able to access it, the groundwater must be in an aquifer.

There is a *lot* of groundwater– some sources estimate there is a thousand times more groundwater than surface water such as lakes and rivers [110]. However, much of it cannot easily be accessed or is contaminated with salt or other chemicals (e.g. silt, road salt, pesticides, metals) which makes it impossible or impractical for us and ecosystems to use [111].

108 Government of Canada, 2013, Water sources: groundwater. https://www.canada.ca/en/environment-climate-change/services/water-overview/sources/groundwater.html. Accessed 2024-03-07.

109 UNESCO, 2023, UN World Water Development Report 2022: Groundwater: making the invisible visible. https://www.unesco.org/reports/wwdr/2022/en/agriculture. Accessed 2024-03-07.

110 United States Geological Survey, 2018, What is Groundwater?. https://www.usgs.gov/special-topics/water-science-school/science/groundwater-what-groundwater. Accessed 2024-03-07.

111 United States Geological Survey, 2018, Groundwater Quality. https://www.usgs.gov/special-topics/water-science-school/science/groundwater-quality. Accessed 2024-03-07.

What happens when groundwater is extracted?

There is a saying that "nature abhors a vacuum" which basically means that where there is a gap, something will fill it – think of water being poured into a glass holding ice-cubes and filling up the gaps between the ice-cubes. When groundwater is extracted from an aquifer, things happen such as the water table dropping. which may cause more water to move in through surface water recharge or from nearby aquifers or the sea. Or, the ground that holds the water may settle and become more compact. If settling happens, the aquifer may no longer hold as much water as it used to.

A lot depends on how quickly that water is extracted. Time is important to the issue in several different ways:

- Groundwater is a significant part of the hydrological cycle so it doesn't stay underground permanently but how long it is down there can range from weeks to millions of years.
- The time it takes for surface water such as rain or snow melt to seep down into the ground and recharge the groundwater aquifers varies widely.
- How quickly the groundwater moves underground from one area to another to replenish a used aquifer also matters.

What happens if groundwater is extracted too quickly?

In many parts of the world, groundwater is being extracted far faster than it can be replaced through natural recharge. In effect, the water currently being used is water which has accumulated in previous years, centuries or millennia depending on how quickly the recharge happens in that area. The effect of this over-extraction is that the amount of groundwater available in that area is reduced and the water table drops further below the surface. The ground level may also drop because of the water extraction. Well known areas of significant storage depletion include the California Central Valley [112] (causing the surface of the earth in some locations to

112 James, I., 2022, Depletion of groundwater is accelerating in California's Central Valley, study finds. https://phys.org/news/2022-12-depletion-groundwater-california-central-valley.html. Accessed 2024-03-07.

settle as much as 8.5 metres [113]) and the Arabian Aquifer System (potentially running dry in ~60-90 years) [114]. It's estimated that:

- 70% of global groundwater extraction is used for agriculture, and
- total global groundwater is being depleted at a rate between 100-200 cubic kilometres per year [115].

Subsidence and Land Degradation

Land subsidence is a phenomenon where the land surface sinks. This often is a result of pore spaces in aquifers collapsing due to reduced water pressure caused when water is removed. This allows the ground above and, in the aquifer, to compact and settle.

This subsidence damages infrastructure such as houses, roads, buildings, bridges and pipelines. This may directly threaten community safety (e.g. Jakarta [116]) and economic development but can also require expensive repair work. Also, land subsidence alters surface drainage patterns which may worsen flooding in low-lying areas and so threaten communities and disrupt ecosystems.

It is currently estimated that almost 2 billion people are at risk from the ground level subsiding (i.e. dropping) more than 5 mm per year [117] although not all of that subsidence is related to groundwater extraction.

Depletion of Water Resources

In the natural state groundwater levels or the water table fluctuate between drawdown through extraction and recharge from rainfall and other naturally occurring inflow. When extraction and recharge are not in balance, problems arise.

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113 Landers, J., 2022, Central Valley subsidence could last longer than expected. https://www.asce.org/publications-and-news/civil-engineering-source/civil-engineering-magazine/article/2022/08/central-valley-subsidence-could-last-longer-than-expected. Accessed 2024-03-11.

114 Mazzoni, A., Heggy, E. and Scabbie, G., 2018, Forecasting water budget deficits and groundwater depletion in the main fossil aquifer systems in North Africa and the Arabian Peninsula. https://doi.org/10.1016/j.gloenvcha.2018.09.009. Accessed 2024-03-07.

115 UNESCO, 2023, UN World Water Development Report 2022: Groundwater: making the invisible visible. https://www.unesco.org/reports/wwdr/2022/en/agriculture. Accessed 2024-03-07.

116 Lin, M.M. and Hidayat, R., 2018, Jakarta, the fastest-sinking city in the world. https://www.bbc.com/news/world-asia-44636934. Accessed 2024-03-12.

117 Bird, H., 2024, Nearly 2 billion people globally at risk from land subsidence. https://phys.org/news/2024-03-billion-people-globally-subsidence.html. Accessed 2024-03-07.

If there is too high a water table flooding may occur in low-lying areas including in home basements and underground parking spaces. As the water table drops, wetlands, rivers, wells and springs dry up, posing a threat to communities reliant on groundwater for drinking and irrigation. This depletion exacerbates water scarcity, particularly in arid and semi-arid regions, where groundwater may be a vital lifeline during droughts.

Socioeconomic Impacts

Agricultural communities reliant on groundwater for irrigation face reduced crop yields and income instability due to declining water availability and crop quality. As water becomes scarcer and more expensive, communities, particularly those in rural and impoverished areas, may struggle to meet their basic needs. This can lead to increased poverty, human migration, changed land use patterns and reduced quality of life especially where water quality is also being compromised. As water stress increases, tension over water resources can arise, both within and between communities, potentially leading to social unrest and instability [118] [119].

Industries dependent on groundwater (e.g. mining, oil and gas, power generation, apparel) [120] for core processes may face production constraints, leading to job losses and economic downturns. Socioeconomic disparities may deepen as marginalized communities bear the brunt of water scarcity and environmental degradation.

Ecosystem Degradation

Groundwater plays a crucial role in sustaining ecosystems, particularly in arid and semi-arid regions where surface water may be scarce. Aquifers feed springs, rivers, and wetlands, supporting a diverse range of plant and animal life across landscapes ranging from mountain valleys, oceans and deserts [121].

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118 Klobucista, C. and Robinson, K., 2023, Water Stress: A Global Problem That's Getting Worse. https://www.cfr.org/backgrounder/water-stress-global-problem-thats-getting-worse. Accessed 2024-03-07.

119 Milne, S, 2021, How water shortages are brewing wars. https://www.bbc.com/future/article/20210816-how-water-shortages-are-brewing-wars. Accessed 2024-03-07.

120 UNESCO, 2023, UN World Water Development Report 2022: Groundwater: making the invisible visible. https://www.unesco.org/reports/wwdr/2022/en/groundwater-and-industry. Accessed 2024-11-13.

121 UNESCO, 2023, UN World Water Development Report 2022: Groundwater: making the invisible visible. https://www.unesco.org/reports/wwdr/2022/en/ecosystems. Accessed 2024-11-13.

Excessive groundwater extraction can reduce the flow of water to these ecosystems, leading to their degradation and potential collapse. For example, reduced water flow can affect the migration, spawning and feeding patterns of fish and other aquatic species, leading to declines in biodiversity and a decrease in climate resilience. Wetlands, which provide critical habitat for numerous species, can dry up resulting in the loss of biodiversity and the ecosystem services they provide, such as water purification, flood control, and carbon sequestration.

Groundwater Contamination

Intensive groundwater extraction increases the risk of groundwater contamination, as pollutants from agricultural runoff, industrial activities, and improper waste disposal infiltrate aquifers more rapidly in depleted systems. Contaminants such as nitrates, pesticides, and heavy metals pose potential health risks to communities reliant on groundwater for drinking water, leading to waterborne diseases and long-term health issues. Further, contaminated groundwater can have cascading effects on ecosystems, affecting aquatic species and soil fertility.

In coastal areas, excess groundwater extraction can result in the inland movement of the freshwater-saltwater interface leading to seawater intrusions into the groundwater. This results in a decreased water quality in the aquifer which can affect the ecosystems dependent on that groundwater and, potentially, render it unfit for consumption. Sea-level rise amplifies this effect.

In summary, groundwater contamination may render the aquifer unusable to humans and the ecosystems that depend on the aquifer [122].

What can be done to mitigate the problems?

The range of uses and users of groundwater and the fact that it is, literally, underground makes groundwater over-extraction challenging to manage. What follows is a high level discussion of some approaches to doing so.

122 Government of Canada, 2017, Groundwater contamination. https://www.canada.ca/en/environment-climate-change/services/water-overview/pollution-causes-effects/groundwater-contamination.html. Accessed 2024-03-13.

Legal and Regulatory approaches

Managing groundwater extraction and addressing the consequences of that extraction requires robust legal and regulatory frameworks to ensure sustainable management of the resource. However, implementing effective regulations faces a number of challenges:

- Water governance is fragmented or incomplete within jurisdictions. The problem is worse for transboundary aquifers where the groundwater is below multiple jurisdictions such as countries. As of 2023, it is thought only 6 transboundary aquifer agreements had been finalised for the estimated 300 transboundary aquifers in the world [123]. Amongst other challenges, reaching inter-jurisdiction agreements can take a long time. Within Canada, for example, the Prairie Provinces Water Board (PPWB) administers a 1969 surface water sharing agreement between Alberta, Saskatchewan and Manitoba (more detail here). The PPWB noted in March 2019 [124] that it was evaluating the possibility of adding transboundary groundwater to the agreement. At time of writing (March 2024), that has yet to happen.
- Many of the factors that affect groundwater extraction (e.g. subsidies for drilling or technology changes decreasing the cost of extraction [125]) lie beyond the remit of typical water management authorities. A broad-based approach is required.
- Competing interests among stakeholders, including agricultural, industrial, and municipal users complicates reaching agreement on how to best use a limited resource. In Alberta, for example, there is an economic and political commitment to developing a new hydrogen-based economy [126]. However, 1) the water required for the proposed hydrogen fuel economy needs to be shared with food producers, existing industry and people, and 2) the water in the southern part of the province (Bow, Oldman and South Saskatchewan Basins) is already fully allocated to existing users so new sharing arrangements will be needed if the new industry is to develop.

123 World Bank, 2022, Water Resources Management. https://www.worldbank.org/en/topic/waterresourcesmanagement. Accessed 2024-03-11.

124 Prairie Provinces Water Board, 2019, Groundwater Activities. https://www.ppwb.ca/groundwater-activities Accessed 2024-03-08.

125 Pearce, F., 2024, How a Solar Revolution in Farming Is Depleting World's Groundwater. https://e360.yale.edu/features/solar-water-pumps-groundwater-crops. Accessed 2024-03-12.

126 Alberta WaterPortal, 2023, Water for Alberta's Hydrogen Economy. https://albertawater.com/alberta-water-blog/water-for-albertas-hydrogen-economy/. Accessed 2024-03-08.

Creating sharing agreements requires collaborative approaches that prioritize long-term sustainability over short-term gains which is not easy when parties to the agreement have pressing needs which require addressing in the short term. The work of the Prairie Provinces Water Board is a promising step in the right direction at the inter-jurisdictional level. At an international level, the United Nations General Assembly has endorsed a set of 19 draft articles related to groundwater for use in the management of transboundary aquifers [127].

Relevant legislation and regulations need to be established *and enforced* to ensure extraction does not exceed recharge rates. This can include permitting systems for well drilling and caps on the amount of groundwater that can be extracted.

Improved understanding and monitoring of groundwater use

It is difficult to effectively manage something which is not well understood. Groundwater data is lacking in many areas, especially in the Global South [128], and that lack of data can make effective management of the resource impossible [129]. A further complication is that even when necessary information is known, it is not always available to elected decision makers (e.g. government ministers) who may be setting policy. Even if the information is available, the decision-makers are typically not groundwater specialists, and so may lack the knowledge of how best to use that information [130].

Groundwater levels and usage must be monitored to detect over-extraction trends early, allowing for timely interventions. Strengthening monitoring and enforcement mechanisms is essential to ensure compliance with regulations and prevent over-extraction and pollution of groundwater resources.

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127 United Nations General Assembly, 2016, The law of transboundary aquifers. http://undocs.org/A/RES/71/150. Accessed 2024-03-08.

128 World Water Quality Alliance, 2021, Assessing Groundwater Quality: A Global Perspective: Importance, Methods and Potential Data Sources. https://groundwater-quality.org/sites/default/files/2021-01/Assessing%20Groundwater%20Quality_A%20Global%20Perspective.pdf. Accessed 2024-06-24.

129 Cherry, J., 2020, The Groundwater Project: Democratizing Groundwater Knowledge. https://doi.org/10.1111/gwat.13029. Accessed 2024-06-24.

130 World Bank, 2022, Water Resources Management. https://www.worldbank.org/en/topic/waterresourcesmanagement. Accessed 2024-03-11.

Groundwater recharge projects

Managed Aquifer Recharge (MAR) is a process whereby aquifers are deliberately recharged in some way [131]. In effect, excess surface water is directed into aquifers during wet periods to enhance groundwater supplies. The suitability of methods depends on factors such as the quality of the water source, local soil and hydrogeology conditions and local land use. For example, there may be little point in recharging an aquifer if the recharge water moves beyond future reach or is contaminated while underground.

It should be noted that MAR is relatively expensive with costs estimated at US$0.04 - US$1.61 per cubic metre of water although it was estimated in 2019 that global MAR has reached 10 cubic kilometres of water [132]. MAR can be done in several ways:

- Injection wells: the water is forcibly injected into an aquifer.
- Created infiltration zones: there is a range of options such as infiltration pools, infiltration galleries, percolation ponds and underground dams [133].

In urban areas, it is possible to encourage the creation of recharge zones, such as parks, stormwater ponds, bioswales, wetlands and open spaces that allow rainwater to percolate into the ground, reducing surface runoff and replenishing groundwater supplies [134]. These spaces may also offer other benefits such as flood mitigation, urban cooling and various mental health benefits such as lowered stress levels. Such nature-based solutions oriented or "Enhanced Aquifer Recharge" approaches tend to be cheaper to implement than more complex MAR mentioned above.

131 Australian Water Association, 2022, Australian exemplars of sustainable, economic managed aquifer recharge. https://www.awa.asn.au/resources/latest-news/australian-exemplars-of-sustainable-economic-managed-aquifer-recharge. Accessed 2024-03-11.

132 Vanderzalm, J., Page. D. et al, 2022, Assessing the costs of Managed Aquifer Recharge options to support agricultural development. https://doi.org/10.1016/j.agwat.2021.107437. Accessed 2024-03-12.

133 CSIRO Chile, n.d., MAR Guides: "Operational framework for artificial aquifer recharge projects". https://research.csiro.au/rag-chile/en/mar-guides-aquifer-recharge/. English summary page – Spanish documentation. Accessed 2024-03-11.

134 Government of Ontario, 2021, Understanding Stormwater Management: An Introduction to Stormwater Management Planning and Design. https://www.ontario.ca/page/understanding-stormwater-management-introduction-stormwater-management-planning-and-design. Accessed 2024-03-11.

Encourage Community-Based Management

Engaging local stakeholders in groundwater management decisions can be done through community-based management programs. This both educates community members and ensures that local needs and knowledge are considered, promoting more sustainable use and conservation of groundwater resources. Developing partnerships with local industries, agricultural sectors, and environmental organizations helps to create a united front in groundwater conservation efforts. Communities can also work to reduce their demands on groundwater by adopting more water-efficient and water conserving practices.

Communities can advocate for the implementation of regulations and policies to control groundwater extraction and prevent over-exploitation of aquifers. Establishing permits, quotas, and pumping restrictions based on sustainable yield assessments helps maintain groundwater levels within safe limits while ensuring equitable access to water resources.

However, community-based approaches on their own will not be enough to address larger-scale issues especially at national and international scales [135].

Conclusion

Groundwater is a hugely important but largely invisible resource which, in many parts of the world, is being used unsustainably. In many respects, groundwater over-extraction is a classic "tragedy of the commons" [136]. However, given the severity of the consequences of damaging or destroying the resource, there is an urgent need to rethink how we manage and use groundwater.

We need to improve our governance of groundwater by ensuring that our governance and water management structures at the international, national, sub-national and community levels of society are fit for purpose. We need to address gaps in our knowledge and ensure that decision-makers are both informed and able

135 World Bank, 2022, Water Resources Management. https://www.worldbank.org/en/topic/waterresourcesmanagement. Accessed 2024-03-11.

136 Banyan, M.E., 2024, Tragedy of the commons. Encyclopedia Britannica. https://www.britannica.com/science/tragedy-of-the-commons. Accessed 2024-03-12.

to use that information. We need to involve all stakeholders in developing sustainable management of a common and shared resource.

Ensuring the sustainable use of groundwater is not only critical for the health of the planet's ecosystems but also for the well-being and prosperity of communities worldwide now and in the future. The balance between utilizing groundwater resources and preserving them for future generations is a delicate one, requiring informed decision-making, cooperation, and commitment at all levels of society.

Call to Action

Become informed! If you're in an area where groundwater is being used, doing nothing will probably result in the unsustainable extraction of groundwater in your area with long-term consequences ranging across issues such as ground subsidence, groundwater contamination, negative economic outcomes and ecological changes. So:

- Do you know what, if anything, groundwater is used for in your community?
- Do you know how much groundwater is used in your community?
- Do you know what is happening to the groundwater in your community?
  - Is the water table stable or changing? If changing, how?
  - Is the water quality changing? If changing, how?
- Do you know how your groundwater is being managed?
- Do you know who uses or depends on groundwater in your community?
- Do you know who is involved in making decisions on groundwater use in your community?
- Also, have a look at our site's entire section dedicated to groundwater which goes into detail on what it is and how it interacts with the surface.

Teaching Ideas

Educating children about the dangers of groundwater over-extraction is crucial for fostering a generation that values and practices sustainable water use. Teachers can implement various education campaigns and activities that are engaging, informative, and age-appropriate. Here are some strategies and ideas:

1. Interactive Workshops and Seminars

- Theme-Based Sessions: Organize workshops that focus on specific themes, such as "The Role of Water in Our Ecosystems" or "How Groundwater Gets Depleted," to provide in-depth knowledge.
- Expert Talks: Invite environmental scientists, water conservationists, or local water authority representatives to talk to students about groundwater issues and conservation efforts.

2. Project-Based Learning

- Water Audit Projects: Encourage students to conduct a water audit of their school or home to identify water usage patterns and potential areas for conservation.
- Community Awareness Campaigns: Guide students in creating campaigns that can be shared with the community through flyers, social media, or school events, spreading awareness about groundwater conservation.

3. Educational Games and Simulations

- Water Cycle Games: Use games that simulate the water cycle to teach children how groundwater is replenished and the impact of over-extraction.
- Role-Playing: Create scenarios where students must manage a community's water resources, making decisions about water use in agriculture, industry, and daily life to understand the consequences of over-extraction.

4. Field Trips and Outdoor Learning

- Visit to a Water Treatment Plant or Aquifer Site: Arrange field trips to places where students can see water management and conservation efforts in action.
- Nature Walks: Organize guided walks in local parks or nature reserves where an educator can discuss natural water cycles, the importance of wetlands, and how they are affected by groundwater levels.

5. Art and Multimedia Projects

- Water Conservation Posters: Have students create posters that highlight the importance of groundwater and tips for conservation, which can be displayed around the school.
- Digital Storytelling: Utilize video making or digital storytelling tools to let students create presentations or short films on groundwater issues, focusing on causes, consequences, and solutions.

6. Science Experiments and Demonstrations

- Aquifer Models: Build simple models of aquifers using clear containers, sand, gravel, and water to demonstrate how groundwater is stored and can be depleted.
- Water Purification Experiments: Conduct experiments that show the process of water purification and discuss how over-extraction affects water quality.

7. Curriculum Integration

- Math and Statistics: Integrate lessons on groundwater using data analysis and statistics, such as calculating water savings from different conservation methods.
- Literature and Writing: Assign readings or creative writing projects related to water issues, encouraging reflection and personal connection to the topic.

8. Use of Technology and Social Media

- Educational Apps and Websites: Leverage interactive online resources and apps designed to teach water conservation and environmental stewardship.
- Social Media Challenges: Create challenges for students to share tips on water conservation or facts about groundwater on social media, using specific hashtags to spread awareness.

By implementing these educational campaigns and activities, teachers can instil an understanding of the critical role groundwater plays in our environment and the importance of conserving this precious resource. Engaging students in hands-on learning, critical thinking, and community involvement prepares them to be informed, responsible citizens who can contribute to sustainable water management efforts.

Habitat Fragmentation

Introduction

To fragment means to separate or break apart [137]. Therefore, habitat fragmentation is the interruption of ecological habitats, involving a change and sometimes a loss of habitat [138]. Habitat fragmentation often occurs when habitats become disconnected because of destruction, either naturally or by human activity [139].

Habitat fragmentation threatens the interconnection of water, communities, and ecosystems. When ecological isolation occurs, and naturally undisturbed areas are exposed to human activities, the fragmented areas change, sometimes losing their ability to support organisms [140]. When a species relies on specific environmental conditions, and habitat fragmentation traps them in a smaller, less suitable habitat, they are at risk of genetic isolation and extinction [141].

Familiar Examples of Habitat Fragmentation

Imagine you lived in a large neighbourhood that had everything you needed nearby, your friends and family, grocery stores, and your school or work. Now, imagine that new roads and buildings were built right in the middle of your access to essential resources, leaving your community divided into smaller regions. This would make it harder for you to live your daily life, needing to learn new routes and take more time

137 Cambridge Dictionary, n.d., Fragmentation. https://dictionary.cambridge.org/dictionary/english/fragmentation. Accessed 2024-06-27.

138 Riva, F., & Fahrig, L. (2022). Author response for "landscape-scale habitat fragmentation is positively related to biodiversity, despite patch-scale ecosystem decay." *Journal of Environmental Management*. https://doi.org/10.1111/ele.14145/v2/response1. Accessed 2024-06-27.

139 Martin, J., 2018, What is habitat fragmentation and what does it mean for wildlife? https://www.woodlandtrust.org.uk/blog/2018/08/what-is-habitat-fragmentation-and-what-does-it-mean-for-our-wildlife/. Accessed 2024-06-27.

140 Haddad, N. M., Brudvig, L. A., et al, 2015-03-20, Habitat fragmentation and its lasting impact on Earth's ecosystems. https://doi.org/10.1126/sciadv.1500052. Accessed 2024-06-27.

141 Parks Canada, 2022-11-19, Habitat loss and fragmentation: Cape Breton Highlands National Park. https://parks.canada.ca/pn-np/ns/cbreton/decouvrir-discover/environ/eco/sensible-sensitive/fragmentation. Accessed 2024-06-27.

to get places. This breaking apart of your community is fragmentation, and this similar process breaks up ecosystems.

This division can impact the wildlife living in these areas and have the following impacts:

- **Restricting Movement and Resource Reduction**
  Just like how the roads and buildings limit your ability to move around, fragmentation restricts the movement of wildlife. Animals can face dangers of difficulty in finding food, mates, and homes.
- **Increased Vulnerability**
  When people or animals are separated from their communities, and in a new environment, they become more vulnerable to diseases and predators.
- **Genetic Impacts**
  Less interaction and mixing of populations reduce the variety and benefits that species would normally be exposed to.

Common Causes of Habitat Fragmentation

Habitat fragmentation in the last century is primarily caused by human activities, but natural events can also cause habitat destruction.

Examples of human-induced habitat fragmentation:

- Clearing land for natural resource extraction or for wood products
- Clearing land to create space for agricultural land
- Clearing land for infrastructure such as roads, train tracks
- Building on land for urbanization and creating communities [142]
- Bottom Trawling (a fishing practice involving towing a net along the ocean floor) in aquatic habitats for human food sources [143]
- Establishing dams

Examples of environmental-induced habitat fragmentation:

- Volcanic eruptions

142 University of California Museum of Paleontology, n.d., Habitat loss/restoration. https://ugc.berkeley.edu/background-content/habitat-loss-restoration/. Accessed 2024-06-27.

143 National Oceanic and Atmospheric Administration, 2022-07-06, Fishing gear: Bottom trawls. https://www.fisheries.noaa.gov/national/bycatch/fishing-gear-bottom-trawls. Accessed 2024-06-27.

- Wildfires
- Tornados
- Tsunamis [144]
- Floods

Anthropogenic (i.e. human caused) influences and natural events disrupting the integrity of habitats leads to ecological and biological consequences. Understanding the origins of habitat fragmentation is essential for developing strategies that mitigate its impacts and preserve biodiversity.

Dams and Habitat Fragmentation

In 1950, there were around 5,000 dams across the world, in 2020 there were 58,7158 in 167 countries, occupying over 300 km^2 [145]. In Canada, there are over 15,000 dams, and 1,157 are considered "large" by the ICOLD (International Commission on Large Dams) definition and are owned by the federal and provincial governments, municipalities, electric utility companies, irrigation districts, and individuals [146]. It is estimated that 48% of all dams worldwide have reduced river connectivity, demonstrating the massive scale of fragmentation occurring across the world [147]. Dams in Canada and across the world are used for many different purposes, including electricity generation, and irrigation. However, dams interrupt waterways, which can impact aquatic species, interrupt migration routes, isolate spawning grounds, and favour species that can quickly adapt to the new habitat caused by the dam [148].

144 University of California Museum of Paleontology, n.d., Habitat loss/restoration. https://ugc.berkeley.edu/background-content/habitat-loss-restoration/. Accessed 2024-06-27.

145 Bohada-Murillo M., Castaño-Villa G.J. and Fontúrbel F.E., 2021, Effects of Dams on Vertebrate Diversity: A Global Analysis. https://doi.org/10.3390/d13110528. Accessed 2024-06-27.

146 Canadian Dam Association, n.d., Dams in Canada. https://cda.ca/dams-in-canada/dams-in-canada. Accessed 2024-06-27.

147 Spinti, R.A., Condon, L.E. & Zhang, J., 2023, The evolution of dam induced river fragmentation in the United States. https://doi.org/10.1038/s41467-023-39194-x. Accessed 2024-06-27.

148 Barbarossa, V., Schmitt, R.J.P., et al, 2020, Impacts of current and future large dams on the geographic range connectivity of freshwater fish worldwide | proceedings of the National Academy of Sciences. https://www.pnas.org/doi/10.1073/pnas.1912776117. Accessed 2024-06-27.

Indigenous Resistance to Dams in Canada

Dams not only fragment plant and animal habitats but also pose threats to human communities. Often when a new dam is proposed in Canada, locals express their concerns. For many Indigenous Peoples in Canada, the presence of dams on or near their territory causes significant threats to their lifestyle. There are a variety of reasons why a local community may be resistant to the implementation or existence of a local dam. Here are a few based on recent events with Indigenous communities in Canada:

- Continued high cost of energy despite local hydropower generation [149]
- Local contamination risk [150]
- Risk of flooding sacred and culturally important lands [151]
- Concerns over ongoing colonial presence on Indigenous land [152]
- Alteration of local ecology, impacting diets, and the food chain [153]

Floods and Habitat Fragmentation

Increases in flood risks due to changes in land use and water cycles suggest that floods will become more frequent and severe [154].

Floods can impact ecosystems by changing where water flows or how it moves, separating habitats, eroding soil, depositing sediments, and destroying vegetation.

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149 Wilt, J., 2019-11-20, "Projects of death": Impact of hydro dams on environment, indigenous communities highlighted at Winnipeg Conference. https://thenarwhal.ca/projects-of-death-impact-of-hydro-dams-on-environment-indigenous-communities-highlighted-at-winnipeg-conference/. Accessed 2024-06-27.

150 Wilt, J., 2019-11-20, "Projects of death": Impact of hydro dams on environment, indigenous communities highlighted at Winnipeg Conference. https://thenarwhal.ca/projects-of-death-impact-of-hydro-dams-on-environment-indigenous-communities-highlighted-at-winnipeg-conference/. Accessed 2024-06-27.

151 Amnesty International USA, 2016-08-08, Massive hydroelectric dam threatens indigenous communities in Canada. https://www.amnestyusa.org/press-releases/massive-hydroelectric-dam-threatens-indigenous-communities-in-canada/. Accessed 2024-06-27.

152 Amnesty International USA, 2016-08-08, Massive hydroelectric dam threatens indigenous communities in Canada. https://www.amnestyusa.org/press-releases/massive-hydroelectric-dam-threatens-indigenous-communities-in-canada/. Accessed 2024-06-27.

153 Hongoltz-Hetling, M. and Seamans, M.G., 2019-12-09, Indigenous activists fight expansion of Canadian hydropower. https://pulitzercenter.org/stories/indigenous-activists-fight-expansion-canadian-hydropower. Accessed 2024-06-27.

154 Talbot, C. J., Bennett, E. M., et al, 2018-05-11, The impact of flooding on aquatic ecosystem services. https://link.springer.com/article/10.1007/s10533-018-0449-7. Accessed 2024-06-27.

When floods change ecosystems, they prompt changes in land use, which can further fragment habitats through isolating species, increasing extinction risk.

Floods are the most common natural hazard in Canada and usually result from heavy rainfall or ice jams although there are other causes of flooding (e.g. storm surge). Flood management and preparation should consider hydrological and ecological dynamics to enhance resilience in flood-prone areas. This link provides flood resource preparation for Canadians [155].

The Edge Effect of Habitat Fragmentation

The 'edge effect' caused by habitat fragmentation demonstrates how the edges of a habitat can vary greatly from the interior. For example, the sunlight, plants, and food sources are different between the interior and edges of habitats. Edge creation can be both positive and negative. For example, browsing wildlife like deer and moose benefit from new growth woody plants. On the negative side, new habitation creates opportunity for rapid growth new species of plants which may be undesirable. Once fragmentation occurs, more edge areas are created, and thus the organisms are faced with altered habitat conditions [156].

Edge creation can be both positive and negative. For example, browsing wildlife such as deer and moose benefit from new growth woody plants. On the negative side, new habitation creates opportunity for rapid growth of new species of plants which may be undesirable.

Water-Related Habitat Fragmentation in Canada

In Canada, habitat fragmentation most commonly occurs because of urban and infrastructure development. Here are some examples highlighting events and projects that have caused water-related habitat fragmentation.

155 Public Safety Canada, 2024-05-06, Get Prepared. https://www.getprepared.gc.ca/index-en.aspx. Accessed 2024-06-27.

156 International Fund for Animal Welfare, 2024, How habitat fragmentation affects animals. https://www.ifaw.org/ca-en/journal/habitat-fragmentation-affects-animals. Accessed 2024-06-27.

Arctic

The basis of life in the Arctic is sea ice, and as the climate changes ice is melting, habitats are shrinking and moving [157]. This type of fragmentation is unique from other examples since it occurs not because of direct development in a specific area, it is induced through the burning of fossil fuels throughout the last century [158] and other factors such as naturally occurring climate cycles (El Niño, La Niña), volcanic eruptions, tectonic plate movement and global deforestation.

Alberta Oil Sands Development

For oil and bitumen (oil sands) to be extracted from the ground, forests need to be cleared, destroying some of the densest habitats on the planet. As you will learn on the 'forests' page, forests play an integral role in the water cycle and further impact larger weather systems.

Hydroelectric Dams in British Columbia

Hydroelectric power involves implementing large dams in waterways to control the flow of water. In British Columbia, hydroelectric dams can block the migration routes of aquatic species, particularly impacting salmon, which are crucial to the livelihoods of Indigenous communities, and the local ecosystem. Dams are important for the energy transition away from reliance on fossil fuels, but they impact the flow, sediment transport, and water temperatures of the water systems they exist in [159]. For example, when sediment cannot continually flow with water through a dam, there becomes build-up of sediment upstream, and a sediment deficiency downstream [160]. Furthermore, the removal of riparian vegetation previously providing shade to the water source can impact temperatures, and the discharged

157 WWF Canada, 2023-11-01, Protecting the warming arctic. https://wwf.ca/habitat/arctic/. Accessed 2024-06-27.

158 Biddlecombe, B. A., Bayne, et al, 2020-04-12, Comparing sea ice habitat fragmentation metrics using integrated step selection analysis. https://doi.org/10.1002/ece3.6233. Accessed 2024-06-27.

159 Water temperature and hydro. (2023). NIWA. https://niwa.co.nz/freshwater/kaitiaki-tools/what-impacts-interest-you/temperature-changes/water-temperature-and-hydro

160 Kondolf, G. M., Gao, Y., Annandale, G. W., Morris, G. L., Jiang, E., Zhang, J., Cao, Y., Carling, P., Fu, K., Guo, Q., Hotchkiss, R., Peteuil, C., Sumi, T., Wang, H.-W., Wang, Z., Wei, Z., Wu, B., Wu, C., & Yang, C. T. (2014). Sustainable sediment management in reservoirs and regulated rivers: Experiences from five continents. Earth's Future, 2(5), 256–280. https://doi.org/10.1002/2013ef000184

water from the dam can be warmer, which impact species and habitats downstream [161].

The St. Lawrence Seaway

Connecting the Atlantic Ocean and the Great Lakes is the St. Lawrence Seaway, a series of locks and channels that has brought significant ecological changes including introducing invasive species and altering natural water flow [162].

Agricultural Drainage in the Prairie Provinces

Agricultural expansion in Saskatchewan and Manitoba has led to the draining of wetlands, reducing the area and increasing the distance between wetland habitats, resulting in habitat fragmentation. Losing the ecosystem services offered by wetlands such as housing biodiversity, flood mitigation, and water purification, impacts the health of aquatic ecosystems [163].

Urban Expansion in Southern Ontario

Development in the Greater Toronto Area has been encroaching on lakes and rivers, fragmenting riparian zones (vegetation between land and a river or stream). Urbanization also increases demand for water, surface runoff challenging natural drainage, and polluting local water chemistry. It also increases the demand for water and supporting infrastructure further challenging historical runoff and natural drainage. As Ontario's population continues to grow by 31.5% (4.6 million) in the next 3 decades, ecological networks can expect to be further interrupted [164].

161 He, T., Deng, Y., Tuo, Y., Yang, Y., & Liang, N. (2020). Impact of the Dam Construction on the Downstream Thermal Conditions of the Yangtze River. International journal of environmental research and public health, 17(8), 2973. https://doi.org/10.3390/ijerph17082973

162 Fisheries and Oceans Canada, 2023-06-15, St. Lawrence Lowlands priority place. https://www.dfo-mpo.gc.ca/species-especes/sara-lep/cnfasar-fnceap/priority-priorite/profiles/lawrence-laurent-eng.html. Accessed 2024-06-27.

163 University of Manitoba, 2018-08-07, For grassland bird conservation, it's not the size that matters. https://news.umanitoba.ca/for-songbird-conservation-its-not-the-size-that-matters/. Accessed 2024-06-27.

164 State of Ontario's Biodiversity, 2021-10-14, Terrestrial landscape fragmentation. https://sobr.ca/indicator/habitat-fragmentation/. Accessed 2024-06-27.

The Role of Habitat Fragmentation in Water Scarcity

Habitat fragmentation can impact water quantity and quality. The following list highlights some ways that habitat fragmentation contributes to water scarcity.

- **Lessened Transpiration**:
  Large areas of vegetation, like forests, are important contributors to the water cycle through transpiration, where water is absorbed by roots and released by leaves into the atmosphere. When vegetated areas are reduced through habitat fragmentation, the local ecosystem can lose humidity and precipitation patterns can change.
- **Increase in Pollution**:
  The human activities that cause habitats to be fragmented can often introduce pesticides, fertilizers, and sediments into an ecosystem. This pollution impacts the quality of water, often making is less safe for drinking, agriculture, and other nearby species to use it.
- **Thermal Pollution**:
  The presence of riparian zones impacts water temperatures for example through providing shade [165]. When habitat fragmentation causes the removal or interruption of riparian zones, and temperatures change, it impacts water quality and aquatic life.
- **Compromised Wetlands**:
  Wetlands are natural water buffers, absorbing water during rainy periods and release during droughts. When habitat fragmentation compromises wetlands, the water quality is reduced.

Habitat Fragmentation's Role in Social Equity

"Social equity" is a concept which is difficult to define precisely and different people define it differently. However, in this context and loosely speaking, social equity can

165 Kalny, G., Laaha, G., et al, 2017-02-03, The influence of riparian vegetation shading on water temperature during low flow conditions in a medium sized river. https://doi.org/10.1051/kmae/2016037. Accessed 2024-06-27.

be considered the "fair treatment of all peoples and communities" [166] or "the recognition and valuing of fair and just relations to promote collective wellbeing" [167].

Habitat fragmentation can impact social equity, affecting communities that may be economically or socially marginalized. Here's how habitat fragmentation contributes to social inequities:

1. Access to Natural Resources

As mentioned, habitat fragmentation often leads to the deterioration of natural resources like clean water, fertile soil, and biodiversity. This can disproportionately affect communities that rely on these resources for their livelihoods, such as through fishing, farming, and gathering.

2. Cultural Impact

Communities often have a cultural tie to the locations they exist in and can have cultural practices involving natural landscapes and species [168]. Habitat fragmentation severs those connections, eroding cultures and diminishing cultural richness.

3. Displacement and Migration

When habitat fragmentation leads to severe environmental changes, communities can be forced to relocate. Low-income populations like coastal or deforested communities become further vulnerable and may be forced to migrate to urban areas, potentially increasing urban inequities.

166 U.S. Climate Resilience Toolkit, 2016-08-30, Social Equity. https://toolkit.climate.gov/topics/built-environment/social-equity. Accessed 2024-06-28.

167 South Australia Certificate of Education, n.d., Social Equity (Version 4.0). https://www.sace.sa.edu.au/web/health-and-wellbeing/stage-2/subject-outline/content/social-equity. Accessed 2024-06-28.

168 The Nature Conservancy. n.d., Partnering with indigenous people and local communities. https://www.nature.org/en-us/about-us/who-we-are/how-we-work/community-led-conservation/. Accessed 2024-06-27.

How Can Communities Contribute to Reducing Water-Related Habitat Fragmentation Concerns?

Through engaging in sustainable practices and supporting conservation initiatives. Here are some strategies communities can adopt.

1. Supporting Restoration Projects

Reconnecting isolated water systems, restoring riverbank vegetation, and implementing wildlife corridors can encourage natural ecological patterns that could have been interrupted through habitat fragmentation.

2. Advocating for Protective Legislation

Lobbying for thorough environmental assessments before implementing new development projects, supporting protected areas, and enforcing regulations in place to limit harmful agricultural and industrial practices. Engaging your community in public consultations, engagement and planning committees advocating for ecological connectivity helps shape urban growth that is conscious of the communities it impacts.

3. Supporting Sustainable Development Planning

Communities can influence local planning decisions to ensure that development is sustainable and minimizes environmental impact. Participating in public consultations, development reviews, and planning committees can help shape urban growth in ways that preserve natural habitats and maintain ecological connectivity.

Conclusion

Habitat fragmentation is a growing global concern as the human population increases and our societies develop and expand into new areas. The fragmentation generally has negative effects on the existing species, especially those species needing large untouched areas in which to live and roam. The fragmentation can also have negative effects on water supply and harm social equity. Often, habitats become fragmented for the benefit of human communities. Understanding the environmental positives and negatives, is important to make informed decisions to mitigate the impacts on aquatic ecosystems, water quality and quantity.

Call to Action

Implement Riparian Buffer Zones

Maintain vegetated buffer zones along waterways to help filter pollutants, stabilize stream banks, reduce erosion, and provide continuous habitat for wildlife, to reduce fragmentation.

Restore and Connect Fragmented Habitats

Engage in local habitat restoration projects to reconnect fragmented habitats, like restoring wetland areas, "daylighting" [169] streams and rivers (e.g. in Toronto [170]), and replanting native vegetation. Restoration improves ecological connectivity and resilience, facilitating wildlife movement and biodiversity.

Advocate for Policy Change

Lobby for local, regional, and national policies that protect water resources and limit activities that lead to habitat fragmentation, like urban development or pollution. Effective policies create legal protections for ecosystems and enforce actions preventing habitat fragmentation.

Participate in Citizen Science Projects

Get involved in projects monitoring water quality, wildlife presence, and habitat changes. Collecting this data can help identify areas at risk of fragmentation, track changes over time, and inform management decisions.

Teaching Ideas

Discussion Questions

- How does habitat fragmentation affect the water cycle in a forest ecosystem? Consider the roles of transpiration, soil moisture, and groundwater recharge.
- Compare the effects of natural and human-induced habitat fragmentation on aquatic ecosystems. Which do you think has a more significant impact, and why?

169 University of Waterloo, n.d., Stream daylighting. https://uwaterloo.ca/stream-daylighting/about. Accessed 2024-06-28.

170 CBC, 2024, Discover where ancient rivers flow under Canadian cities. https://newsinteractives.cbc.ca/features/2024/daylighting-rivers/. Accessed 2024-06-28.

- Imagine you are an urban planner; how would you design a new development project to minimize habitat fragmentation and its effects on local water bodies?
- Discuss the ethical responsibilities of communities and governments in preventing habitat fragmentation. Who should be primarily responsible for maintaining ecosystem integrity, and why?
- Evaluate the effectiveness of a real-world example where a community has taken steps to mitigate the effects of habitat fragmentation. What were the outcomes, and what could have been done differently?
- How might scientists measure the impact of habitat fragmentation on a specific aquatic species? What types of data would they need to collect?
- "All new infrastructure projects should be required to include an environmental impact assessment that specifically addresses habitat fragmentation." Agree or disagree and provide reasons for your position.
- Reflect on your local area's ecosystem. Can you identify any signs of habitat fragmentation? What changes would you propose to help mitigate these effects?

Activities

1. Ecosystem Simulation Game

Create a role-playing simulation game where students manage their own ecosystems. They must make decisions regarding land use, water management, and species protection to keep their ecosystems healthy while balancing economic and social needs. The objective is to teach students about the complexities of ecosystem management and the consequences of habitat fragmentation.

2. Habitat Fragmentation Experiment

Use a large tray filled with mixed seeds (representing different species) and soil. Have students build barriers with cardboard to simulate roads, urban areas, and other forms of fragmentation. Observe how water flow (using a spray bottle) changes seed dispersal and soil erosion. This demonstrates how habitat fragmentation can affect plant distribution and water dynamics.

3. Debate on Land Management Policies

Organize a debate on different land management strategies and their potential impacts on habitat fragmentation and water resources. Topics could include the construction of wildlife corridors, urban green spaces, or the implementation of

sustainable agriculture practices. This enhances critical thinking and public speaking skills while exploring practical solutions to habitat fragmentation.

4. Interactive Documentary Project

Have students create short documentaries or digital presentations on specific case studies related to habitat fragmentation. They could interview local experts, conduct field research, and use multimedia tools to present their findings. This encourages creative expression and in-depth research skills while educating peers about habitat fragmentation.

5. Restoration Workshop

Partner with local environmental organizations to participate in a habitat restoration project, such as planting native vegetation, removing invasive species, or cleaning up waterways. This provides hands-on experience with conservation efforts and illustrates the importance of active ecosystem management to counteract habitat fragmentation.

6. Site Visits

Find a local real-life example that can form the basis of how your class team would develop that project that incorporates concepts and experiences presented in this chapter. For example, the Ricardo Ranch Project in Calgary.

Invasive Species

Invasive species represent a significant ecological challenge, intertwining complex issues of biodiversity loss, ecosystem disruption, and impacts on human activities.

What are Invasive Species?

An invasive species is an organism that is not native to the location it is living in, and has a tendency to spread, causing harm to the environment, human health, or the economy. Thriving beyond their natural habitats, these species can disrupt local ecosystems and outcompete native organisms for resources [171].

The introduction of invasive species to new areas is often helped by human activities. Whether accidentally, through global shipping or not cleaning equipment such as watercraft and fishing gear [172], or intentionally, through trading or horticulture, these species find new territories without their natural predators [173]. It is important to note that invasive species also include those native to parts of Canada that have been introduced or expanded into areas outside their historical range [174].

Invasive species are often viewed negatively, but it's important to remember that species moving into new areas is a natural process. However, a problem arises when humans speed up this process, introducing many species to new places quickly. This can lead to environments becoming too similar worldwide and might even cause some ecosystems to fail in ways we've never seen before [175].

171 National Wildlife Federation, n.d.. Invasive species. https://www.nwf.org/Educational-Resources/Wildlife-Guide/Threats-to-Wildlife/Invasive-Species. Accessed 2024-04-10.

172 Fisheries and Oceans Canada, 2024, Clean, Drain, Dry and Decontaminate. https://www.dfo-mpo.gc.ca/species-especes/ais-eae/prevention/clean-drain-dry-decontaminate-lavez-videz-sechez-decontaminez-eng.html. Accessed 2024-12-15.

173 Coastal Conservation, 2015 (May 21), Invasive species impacts eradication: Coastal conservation. Coastal Conservation | Restoring the Balance. https://coastalconservation.ca/invasive-species/invasive-species-in-canada. Accessed 2024-04-10.

174 Government of Canada, F. and O. C., 2019 (May 3), Government of Canada. Government of Canada, Fisheries and Oceans Canada, Communications Branch. https://www.dfo-mpo.gc.ca/species-especes/ais-eae/about-sur/index-eng.html. Accessed 2024-04-10.

175 SOKA University, n.d., Effects of invasive species on water quality in freshwater ecosystems by Laura Heller '20. Effects of Invasive Species on Water Quality in Freshwater Ecosystems by Laura Heller '20 | Soka University of America. https://www.soka.edu/about/20th-anniversary-anthology/creative-coexistence-nature-humanity/effects-invasive-species. Accessed 2024-04-10.

Other words for 'invasive' species can be 'non-native', 'non-indigenous', 'alien', 'introduced' or 'exotic' [176].

Once established, invasive species can swiftly outcompete native flora and fauna, leading to decreased biodiversity [177]. They can also introduce diseases, modify habitats, and disrupt food webs. Their economic impact can be profound, affecting agriculture, fisheries, and forestry, with costs running into billions annually for management and lost revenue [178]. Aquatic invasive species are notorious for altering water quality and habitat conditions, posing threats to both native species and human health.

Rapid introductions of species by humans can cause ecosystem homogenization or uniqueness, and potential collapse, yet it's crucial to balance the dialogue on invasive species. Understanding the historical context of native versus non-native species and focusing on the specific ecological impacts of invasive species can lead to effective conservation strategies [179].

Understanding the Impact of Invasive Species

Invasive species threaten diversity in our planet's ecosystems. Aquatic invasive species impact our aquatic resources by reducing biodiversity and habitat quality, outcompeting native species, challenging aquatic industries, harming recreational activity, and permanently altering ecosystems [180].

176 Adams, M. J., 2023, (November 14), The role of invasive species on Watershed Health. Mclean Water. https://mcleanwater.org/?page_id=1037. Accessed 2024-04-10.

177 National Geographic,.n.d., People and invasive species. https://education.nationalgeographic.org/resource/people-and-invasive-species/. Accessed 2024-04-10

178 Food and Agriculture Organization, 2017, The impact of disasters and crises on agriculture and food security. https://www.fao.org/3/I8656EN/i8656en.pdf. Accessed 2024-04-10.

179 Jeschke, J., Bacher, S., et al, 2014, Defining the impact of non-native species. Conservation Biology, 28(5), 1188–1194. https://doi.org/10.1111/cobi.12299. Accessed 2024-04-10.

180 Fisheries and Oceans Canada, 2019, (May 3). About aquatic invasive species. https://www.dfo-mpo.gc.ca/species-especes/ais-eae/about-sur/index-eng.html. Accessed 2024-04-10.

The Disruption of Invasive Species

Increased Water Consumption

Some invasive species use water more efficiently than native species, or require more water to thrive. For example, certain types of invasive plants, such as Phragmites (a type of reed) or Tamarisk (also known as salt cedar), consume large amounts of water [181]. When these species establish themselves along riverbanks or in wetlands, they can reduce the amount of water available in these ecosystems by absorbing more water from the soil and groundwater than native plants. This increased consumption can lead to lower water levels in streams, rivers, and lakes, contributing to water scarcity.

Alteration of Waterways

Invasive species can alter the structure of water bodies and their natural flow. Aquatic plants like Hydrilla or Eurasian watermilfoil can grow rapidly, forming thick mats that cover water surfaces [182]. These mats can impede water flow, leading to increased evaporation and decreased water availability downstream. This alteration of water flow and sediment affect the recharge of aquifers, further impacting water availability.

Impacts on Water Quality

Invasive species can degrade water quality, which indirectly contributes to water scarcity by limiting 'usable' water resources. For example, the decay of plant material from invasive species can deplete oxygen levels in water bodies, causing dead zones where fish and other aquatic life cannot survive [183]. This process, known as eutrophication, requires water treatment to make the water suitable for human consumption and agricultural use, thus reducing the effective supply of water.

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181 Invasive Species Centre, 2024-03-25, Invasive phragmites – profile and resources. https://www.invasivespeciescentre.ca/invasive-species/meet-the-species/invasive-aquatic-plants/phragmites/. Accessed 2024-04-10.

182 Invasive Species Centre, 2022-05-09, Eurasian watermilfoil – profile and resources. https://www.invasivespeciescentre.ca/invasive-species/meet-the-species/invasive-aquatic-plants/eurasian-water-milfoil. Accessed 2024-06-26.

183 Environmental Protection Agency, 2024-01-03, The Effects: Dead Zones and Harmful Algal Blooms. https://www.epa.gov/nutrientpollution/effects-dead-zones-and-harmful-algal-blooms. Accessed 2024-04-10.

Introducing New Contaminants

Some invasive species can introduce or concentrate pollutants within ecosystems. For example, certain invasive mussels, like zebra and quagga mussels, filter and accumulate toxins and pollutants from the water, which can then be passed up the food chain, impacting wildlife and potentially human health [184]. Their ability to bioaccumulate pollutants can turn them into vectors for water contamination.

Competition for Resources

Invasive species compete with native species for essential resources like food, water, and habitat space. Because invasive species can sometimes be more aggressive or efficient in resource use, or lack local natural predators, native species may be outcompeted [185]. This competition can lead to the decline or extinction of native species (e.g. ash trees from the emerald ash borer [186]), especially those which are already vulnerable or endangered.

Disease and Parasites

Invasive species can introduce new diseases and parasites to native species that have no immunity or defence [187]. These diseases can destroy native populations, further reducing biodiversity.

Genetic Pollution

Invasive species can hybridize with closely related native species, leading to genetic pollution. This hybridization can dilute the genetic distinctiveness of native species, potentially reducing their viability and adaptability to changing environmental conditions [188]. Over time, this can lead to a loss of biodiversity as unique genetic lineages are lost.

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184 Center for Invasive Species Research, 2022-09-28, Quagga & zebra mussels. https://cisr.ucr.edu/invasive-species/quagga-zebra-mussels. Accessed 2024-06-26.

185 Leger, E.A. and Espeland, E.K., 2010, Coevolution between native and invasive plant competitors: implications for invasive species management. DOI: 10.1111/j.1752-4571.2009.00105.x. Accessed 2024-06-26.

186 Invasive Species Centre, n.d., Emerald Ash Borer. https://www.invasivespeciescentre.ca/invasive-species/meet-the-species/invasive-insects/emerald-ash-borer/. Accessed 2024-06-26.

187 Pavid, K., 2020-07-01, What are invasive species? https://www.nhm.ac.uk/discover/what-are-invasive-species.html. Accessed 2024-04-10.

188 Todesco, M., Pascual, M.A., et al, 2016-02-22, Hybridization and extinction. https://doi.org/10.1111/eva.12367. Accessed 2024-06-26.

Economic Challenges Caused by Invasive Species

The unchecked growth of invasive species can harm crops, fisheries, and forests, directly affecting industries relying on these resources. In aquatic environments, invasive species like zebra mussels can clog water intake pipes, affecting water treatment and power plants, which can lead to expensive maintenance and repairs [189]. Invasive species can harm native wildlife and plants, affecting tourism and outdoor recreation industries. Overall, the management, control, and eradication of invasive species can require significant financial investment, adding to the economic burden they impose on communities.

Aquatic invasive species bring significant economic costs, impacting essential services and industries. They clog water lines leading to dams, power stations, wastewater treatment plants, and drinking water facilities, causing blockages that require costly cleaning and increasing operational expenses [190]. These species also foul aquaculture operations, like shellfish, necessitating expensive control, monitoring, and eradication measures [191]. Businesses dependent on natural water bodies, such as tourism, fisheries, and aquaculture, face decreased revenue due to these invasive species. Recreational activities, including fishing, swimming, boating, and tourism, suffer as these species damage infrastructure, make waters unsuitable for various activities, and displace native species crucial for recreational fishing.

Canadian Examples of Invasive Species

Canada faces challenges from invasive species that threaten its waterways ranging from affecting the health of ecosystems to impacting the economy and recreational activities. Here are some Canada-specific examples of water-related invasive species:

189 Don't Move A Mussel, n.d., Don't move a mussel: News releases & coverage. https://dontmoveamussel.ca/resources/in-the-news-copy. Accessed 2024-06-26.

190 Environmental Protection Agency, 2023-06-22, Water Treatment and Waste Management. https://www.epa.gov/emergency-response-research/water-treatment-and-waste-management. Accessed 2024-04-10.

191 Fisheries and Oceans Canada, 2019-05-03, About aquatic invasive species. https://www.dfo-mpo.gc.ca/species-especes/ais-eae/about-sur/index-eng.html. Accessed 2024-06-26.

Zebra and Quagga Mussels

Zebra and quagga mussels are small, live in freshwater, and can quickly colonize lakes and rivers. Originating from Eastern Europe, these mussels were first discovered in the Great Lakes in the 1980s [192]. They filter plankton from the water, which can disrupt local food webs and harm native species. Additionally, they clog water intake pipes, affecting municipal water supply systems, power plants, and irrigation infrastructure, leading to high maintenance costs.

European Watermilfoil

European watermilfoil is an invasive aquatic plant that forms dense mats on the surfaces of water bodies, hindering recreational activities such as swimming and boating. It can also outcompete native aquatic plants, alter habitats for fish and other wildlife, and reduce biodiversity [193]. Once established, it is extremely difficult to eradicate and spreads quickly when carried by boats to new locations.

Asian Carp

Asian carp is a collective term for species such as bighead, silver, grass, and black carp [194]. These fish are highly adaptable and fast-growing, posing a significant threat to the Great Lakes and other Canadian waters. They compete with native fish for food and habitat, leading to the decline of native species. The presence of Asian carp in Canadian waters could severely impact commercial and recreational fishing industries [195].

192 United States Geological Survey, n.d., What are zebra mussels and why should we care about them? https://www.usgs.gov/faqs/what-are-zebra-mussels-and-why-should-we-care-about-them. Accessed 2024-06-26.

193 Invasive Species Centre, 2022-05-09, Eurasian watermilfoil – profile and resources. https://www.invasivespeciescentre.ca/invasive-species/meet-the-species/invasive-aquatic-plants/eurasian-water-milfoil. Accessed 2024-06-26.

194 Invasive Species Centre, 2023-12-04, Asian carps – profile and resources. https://www.invasivespeciescentre.ca/invasive-species/meet-the-species/fish-and-invertebrates/asian-carps. Accessed 2024-06-26.

195 Asian Carp Canada, 2021-03-25, Socio-economic impact of the presence of Asian carp in the Great Lakes Basin. https://www.asiancarp.ca/impacts/risk-assessments/socio-economic-impact-of-the-presence-of-asian-carp-in-the-great-lakes-basin. Accessed 2024-06-26.

Round Goby

The round goby is a small, bottom-dwelling fish first discovered in the Great Lakes in the 1990s, likely introduced through ballast water from ships [196]. Round gobies eat the eggs and young of native fish and compete with them for food and habitat. They are also a nuisance for anglers, as they can dominate bait traps and hooks intended for other species [197].

The Government of Canada uses 4 pillars to approach aquatic invasive species management [198].

1. **Prevention**:
   Taking proactive steps to stop aquatic invasive species from entering new environments in the first place.
2. **Early Detection**:
   Quickly identifying newly introduced aquatic invasive species to eliminate them before they can establish a foothold.
3. **Response**:
   Employing comprehensive measures to remove established invasive species from an ecosystem and rehabilitate the environment to its original condition.
4. **Control and Management**:
   Implementing strategies to lessen the effects of invasive species populations that are too widespread to be completely removed.

Communities' Role

Community awareness of aquatic invasive species is vital since they are the first line of defence in preventing the introduction and spread of new species. Knowledge about how invasive species relocate and the potential harm they can cause enables individuals to take proactive measures, such as thoroughly cleaning boats and equipment.

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196 Government of Ontario, 2022-07-28, Round goby. https://www.ontario.ca/page/round-goby. Accessed 2024-06-26.

197 Somers, C. M., Lozer, M. N., et al, 2003, The invasive round goby (Neogobius Melanostomus) in the diet of nestling double-crested cormorants (Phalacrocorax auritus) in Hamilton Harbour, Lake Ontario. https://doi.org/10.1016/s0380-1330(03)70446-8. Accessed 2024-06-26.

198 Fisheries and Oceans Canada, 2019-05-03, About aquatic invasive species. https://www.dfo-mpo.gc.ca/species-especes/ais-eae/about-sur/index-eng.html. Accessed 2024-06-26.

Additionally, early detection by vigilant community members can prompt quick management actions to eradicate an invasive species before it becomes established. Community engagement is crucial for the protection of local ecosystems, which face threats from reduced biodiversity, altered habitats, and the endangerment of native species due to invasions. Beyond environmental concerns, aquatic invasive species can inflict substantial economic damage, impacting water infrastructure, fisheries, tourism, and recreational activities. The economic health of communities often depends on the vitality of these sectors, underscoring the importance of community support for control measures. Some invasive species present direct threats to public health by carrying diseases or creating unsafe conditions in water bodies.

Discussion Questions

These questions aim to encourage students to think critically about invasive species' impact on ecosystems, economies, and societies.

1. How to identify and where to look for invasive species
2. How do we differentiate between non-native and invasive species? Consider the characteristics that make a species invasive rather than simply a non-native addition to an ecosystem.
3. What are some specific examples of invasive species in your region, and what impacts have they had on local ecosystems and communities? Discuss both the ecological and economic impacts.
4. In what ways have human activities contributed to the spread of invasive species? Consider both intentional and unintentional introductions.
5. How does the loss of biodiversity due to invasive species affect ecosystem services and human well-being? Provide examples of ecosystem services that have been disrupted by invasive species.
6. Discuss the various methods used to control invasive species. What are the challenges and benefits of these methods? Consider mechanical, chemical, and biological control strategies.
7. Is it more effective to prevent the introduction of invasive species or to control them once they have been introduced? Debate the pros and cons of prevention versus control measures.

8. Are there ethical considerations in the management and control of invasive species? For example, are there implications of using poisons or introducing predator species as control methods?
9. How can trans boundary cooperation in the fight against invasive species? Discuss the importance of international agreements and local community actions in managing invasive species.
10. Explore the relationship between climate change and invasive species. How might changing climates affect the spread and impact of invasive species?
11. What future challenges do you predict in managing invasive species? Consider technological advances, climate change, and global trade.

Teaching Ideas

1. Invasive Species "Detective" Field Trip

Organize a field trip to a local natural area or park. Prior to the visit, have students research invasive species known in the area. During the field trip, students can identify invasive species, document their findings with photographs, and note how these species interact with their surroundings.

Learning Objectives:

- Identify invasive species in the field.
- Understand the real-world impacts of invasive species on local ecosystems.
- Develop research and observation skills.

2. Debate: Management Strategies for Invasive Species

Divide students into groups and assign each group a position on various management strategies (e.g., mechanical removal, chemical treatment, biological control). Students research their assigned strategy, prepare arguments, and debate its merits and drawbacks in class.

Learning Objectives:

- Explore the complexities of managing invasive species.
- Develop critical thinking and public speaking skills.
- Understand the ethical, ecological, and economic dimensions of invasive species management.

3. Invasive Species and the effect on our lives and livelihood

Students are assigned roles as various stakeholders (e.g., farmers, conservationists, government officials) in a scenario involving invasive species and their impact on ecosystem services. They must discuss and propose solutions to manage the invasive species, considering the needs and concerns of their stakeholder group.

Learning Objectives:

- Appreciate the diverse perspectives on invasive species management.
- Understand the concept of ecosystem services and how invasive species affect these services.
- Develop negotiation and collaboration skills.
- The role of ongoing change and adaptation in the natural world.

4. "Design Your Own Invasive Species" Art Project

Students create a fictional invasive species, considering factors such as adaptations, spread mechanisms, and potential impacts on ecosystems. They illustrate their species and present it to the class, explaining how it would fit into and potentially alter its new environment.

Learning Objectives:

- Understand the characteristics that make a species invasive.
- Foster creativity and apply biological concepts in a fictional context.
- Improve presentation skills and scientific communication.

5. Interactive Map Project

Using digital tools or physical maps, students can create a map showing the spread of a particular invasive species over time in their region or country. They can research the history of the species' introduction, its spread, and its ecological and economic impacts.

Learning Objectives:

- Use technology to visualize environmental change.
- Understand the spread and impact of invasive species on a larger scale.
- Develop research and data interpretation skills.

6. Invasive Species Removal Volunteer Day

Collaborate with a local environmental organization to participate in an invasive species removal effort. Students learn about the species they are removing, the reasons for its management, and safe removal techniques.

Learning Objectives:

- Contribute to local conservation efforts.
- Learn about habitat restoration and the importance of native species.
- Foster a sense of community and environmental stewardship.

Social Equity

Understanding Social Equity

Social equity refers to the fair and equitable distribution of environmental benefits and burdens across all members of society, regardless of their background, race, gender, or economic status [199]. It emphasizes the need for all individuals to have equal access to resources, opportunities, and rights, aiming to eliminate disparities and injustices in society.

Social Equity and the Environment

When we talk about social equity and the environment, we're looking at how environmental policies, practices, and changes impact different communities in various ways. Not everyone experiences environmental benefits (like clean air and water, green spaces, and healthy ecosystems) or burdens (such as pollution, natural disasters, and the effects of climate change) equally [200].

Imagine two neighbourhoods: one is a wealthy area with lots of green spaces, trees, and access to clean water; the other is a less wealthy area, with few parks, industrial facilities nearby, and poorer water quality. Despite living in the same city, residents in these neighbourhoods have very different access to clean air, water, and recreational spaces. This disparity is a simple example of a lack of social equity in their environments.

The fairness in how environmental benefits and burdens are distributed within society matters because it directly affects health and quality of life. When certain groups bear the brunt of environmental negatives (like pollution or lack of access to clean water) while others enjoy more of its positives, it leads to social and health inequities.

199 United Way NCA, 2023-04-20, What is social equity? Definition & Examples. https://unitedwaynca.org/blog/what-is-social-equity/. Accessed 2024-03-19.

200 Garcia, M., 2024-02-05, The importance and benefits of environmental justice and Social Equity: EnvironBuzzTM Magazine. EnvironBuzz. https://environbuzz.com/the-importance-and-benefits-of-environmental-justice-and-social-equity. Accessed 2024-03-19.

The impacts of environmental changes on equity-seeking communities

Equity-seeking communities often suffer more significantly when environmental changes such as altered hydrological cycles, reduced water quality, disruption of aquatic habitats, deforestation, changes in precipitation patterns, and increased runoff and erosion occur. These impacts can compound with existing vulnerabilities, including limited access to resources, infrastructure, and political power to advocate for change.

Examples of how environmental changes can affect equity-seeking communities:

- **Altered Hydrological Cycles:**
  Changes in how water moves through nature can cause less water to be available or make it harder to predict when and where it will rain or snow or melt. This can affect drinking water, farming, and keeping clean. Communities that depend on natural water sources might not have enough, which can hurt their health and food supply [201].
- **Reduced Water Quality:**
  Pollution and reduced water quality can create serious health problems for people who depend on rivers, lakes, and groundwater for drinking, cooking, and bathing. Without proper water treatment facilities, these communities are at risk of getting sick from waterborne diseases [202].
- **Disruption of Aquatic Habitats:**
  Damage to rivers, lakes, and other water bodies affects fish populations and biodiversity. This can hurt communities that reply on fishing for food and jobs. With fewer aquatic species and other resources, people may struggle to eat and earn money [203].
- **Deforestation:**
  Forests are a source of medicinal plants, food, and resources for communities. Cutting down forests and not replanting them leads to the loss of these resources, including a sustainable source of wood for communities that rely on them for food and work. Forests also provide ecosystem services, which

201 UN Water, n.d., Water and sustainable development. United Nations. https://www.un.org/waterforlifedecade/water_and_sustainable_development.shtml. Accessed 2024-03-19.

202 National Geographic, n.d., Water inequality. Education. https://education.nationalgeographic.org/resource/water-inequality/. Accessed 2024-03-19.

203 Furman, K. L., Harlan, S. L., Barbieri, L., & Scyphers, S. B., 2023, Social Equity in shore-based fisheries: Identifying and understanding barriers to access. Marine Policy, 148, 105355. https://doi.org/10.1016/j.marpol.2022.105355. Accessed 2024-03-19.

are the direct and indirect benefits that ecology provides humans [204], such as keeping the soil in place and water regulation. If the forests are gone, those added benefits are also gone, and communities can face more problems from changes in their environment [205].

- **International Cooperation and Solidarity**:
  Water scarcity, or "water shortage", is a global issue that extends across national boundaries and requires international cooperation. In fact, globally, 2 billion people or one-quarter of the world's people do not have access to safe drinking water in their homes [206]. Social equity emphasizes the importance of wealthier nations supporting less wealthy countries in developing water infrastructure and sharing technological information to help manage water resources effectively and equitably.
- **Access to Clean Water and Sanitation**:
  Clean water lets people bathe, handle waste, clean, and cook safely without the risk of getting sick or the impacts of poor hygiene. Nearly half of the world's population - 46% - do not have access to safely managed sanitation [207]. Cleaning up and preventing water pollution is important for public health, as waterborne diseases are more prevalent in areas with poor water quality.

Ensuring everyone has access to clean water is not just about treating and preventing pollution. It is also about building and maintaining the infrastructure needed to deliver safe water and sanitation services to every community, while making sure they last over time, regardless of the community's socioeconomic status.

The effects of these environmental changes on poor communities demonstrates the need for integrated, equitable approaches to environmental management and development. To help these vulnerable communities, policies are needed that help provide resilience to affected communities. This involves improving access to clean

204 Ecosystem Services | USDA Climate Hubs, n.d., Www.climatehubs.usda.gov. https://www.climatehubs.usda.gov/ecosystem-services. Accessed 2024-12-04.

205 Fransen, B., 2023-03-30, How do reforestation and Social Justice Intersect?. EcoMatcher. https://www.ecomatcher.com/how-do-reforestation-and-social-justice-intersect/. Accessed 2024-03-19.

206 Centre for Disease Control and Prevention, 2022-05-31, Global Wash Fast Facts. Centers for Disease Control and Prevention. https://www.cdc.gov/healthywater/global/wash_statistics.html. Accessed 2024-03-19.

207 Omer, S., 2024-03-06, Global water crisis: Facts, faqs, and how to help. World Vision. https://www.worldvision.org/clean-water-news-stories/global-water-crisis-facts. Accessed 2024-03-19.

water, supporting sustainable agriculture, and reducing disaster risk, within the framework of social equity and environmental justice.

Water-related social equity concerns in Canada

In Canada, water-related social equity concerns highlight the discrepancies in access to clean and safe water, the impacts of industrial activities on water resources, and the involvement of communities in managing and governing their own water resources. Some specific examples include:

- **Indigenous Communities and Boil Water Advisories**:
  Many Indigenous communities in Canada have been under long-term boil water advisories. Despite Canada having the world's third-largest freshwater reserves, 30 long- term drinking water advisories remain active on public systems on reserves [208].
- **Access to Water in Remote Communities**:
  Remote and northern communities in Canada often face challenges in accessing reliable and safe water sources. Because of their geography, it can be difficult to find local water sources, or to build appropriate water treatment plants. Hiring and training local operators, maintaining infrastructure, and the high costs associated with remote communities results in an imbalance in water quality and access that are not faced by less remote and southern communities [209].
- **Industrial Pollution and Water Contamination**:
  In regions with significant industrial activity [LINK] (click here to learn more about water and industry), such as Alberta's oil sands, water contamination from chemicals and waste can lead to pollution of rivers and groundwater, affecting both the environment and the health of nearby residents [210].
- **Climate Change and Water Scarcity**:
  Climate change is likely to worsen water scarcity in British Columbia and the Prairies, specifically due to changing precipitation patterns affecting

208 Indigenous Services Canada, 2024-11-07, Ending long-term drinking water advisories. https://www.sac-isc.gc.ca/eng/1506514143353/1533317130660?fbclid=IwZXh0bgNhZW0CMTAAAR0ydZnwzdBgESHdRU0NNyshxXQ7M4Xe4Ew8-VEQCFrHiide8xbo7g4chNI_aem_YogkDnL410zdTC_P4aBCOw. Accessed 2024-12-15.

209 Belouizdad, S., 2023-12-07, An overview of water delivery systems and barriers to provision: MacDonald-Laurier Institute. Macdonald. https://macdonaldlaurier.ca/overview-of-water-delivery-systems-and-barriers-to-provision/. Accessed 2024-03-19.

210 University of Alberta, n.d., The impacts of industry on water in Alberta. https://sites.ualberta.ca/~ersc/water/industrial.htm. Accessed 2024-03-19.

agriculture, hydropower, and community water supplies [LINK] (click here to learn about drought). The uneven distribution of these impacts raises questions about social equity, as some communities are less equipped to adapt to these changes [211].

Community Involvement in Reducing Water-Related Social Inequities

Overcoming inequity requires commitment from everyone involved—governments, businesses, non-profits, and community members. Here are several ways that communities can contribute to reducing inequities:

- **Community-Led Water Monitoring:**
  Communities can organize local water monitoring initiatives to track water quality and quantity. This grassroots approach empowers residents to collect data, identify pollution sources, and understand seasonal variations. By monitoring their water resources, communities can advocate for better water management practices based on concrete evidence.
- **Development of Local Water Governance Structures**:
  Water management policies and regulations are often made at provincial, territorial, or federal levels. Involving community members in water governance adds local voices, concerns, and ideas to decision-making processes. This can be achieved through the formation of water user associations, community advisory boards, or local watershed management councils. Inclusive governance, which is the idea of including all members of a community, helps ensure that policies and projects do not disproportionately impact vulnerable populations.
- **Advocacy and Collaboration**:
  Communities can advocate to governmental bodies for policies that address water-related social equity concerns, like investments in infrastructure to ensure all have access to clean, affordable water. Collaboration with non-governmental organizations, academic institutions, and government agencies can amplify their voice and impact, pushing for systemic changes that address the root causes of inequity.

211 United Nations, n.d., Water – at the center of the Climate Crisis. https://www.un.org/en/climatechange/science/climate-issues/water. Accessed 2024-03-19.

- **Implement Rainwater Harvesting and Greywater Recycling**:
  Communities can implement rainwater harvesting systems and greywater recycling, especially in areas facing water scarcity or quality issues. These systems are an alternative source of water for non-potable uses, reducing the demand on municipal systems and helping to alleviate water stress.
- **Promote No Net Loss of water and net addition of water in community development**:
  The underlying concept of "no net loss" is that any development in a community should, at a minimum, not result in a net (or overall reduction) in the availability of something to that community. In the context of water, the concept means that that any water consumed in the development needs to be replaced.

  A practical application of this concept is often seen in the context of wetlands. Wetlands, for various reasons, have sadly often been destroyed and replaced by new development such as subdivisions. More recent approaches (e.g. City of Calgary's wetland policy [212], Government of Quebec [213], Government of British Columbia [214]) are to protect (preferable) or replace wetlands and so preserve the many benefits offered by those wetlands..
- **Promoting Indigenous and Local Knowledge**:
  Indigenous and local knowledge systems offer valuable insights into sustainable water management practices that have been refined over generations. Recognizing and integrating this knowledge into broader water management practices can contribute to more resilient and equitable water systems.

By engaging in these activities, communities can begin to address immediate water-related social equity concerns and invest in the long-term sustainability and resilience of their water resources. Community-driven initiatives ensure that solutions are locally relevant, culturally appropriate, and sustainable, marking a significant step toward addressing global water equity challenges.

212 The City of Calgary, 2004, Calgary Wetland Conservation Plan. https://www.calgary.ca/parks/wildlife/wetlands-conservation.html. Accessed 2024-12-04.

213 Government of Quebec, n.d., Conservation of Wetlands and Bodies of Water. https://www.environnement.gouv.qc.ca/eau/rives/milieuxhumides-en.htm. Accessed 2024-12-06.

214 Government of British Columbia, 2019, No Net Loss of Wetland Act. https://www.bclaws.gov.bc.ca/civix/document/id/bills/billsprevious/4th41st:m215-1. Accessed 2024-12-06.

Further Reading

Drought
Hydrologic Cycle
Hydrologic Modelling in Alberta
Water Quality
Deforestation
Transboundary Water
Transboundary Water in Alberta
Boil Water Advisories

Teaching Ideas

These interactive learning opportunities provide students with a comprehensive understanding of social equity in the context of environmental issues, encouraging them to become informed and active participants in their communities.

Simulation Games

Equity and Resources Distribution Simulation: Create a simulation game where students are divided into groups representing different communities with varying levels of resources, access to clean water, and exposure to environmental burdens. The game involves negotiating for resources, facing simulated environmental challenges, and making decisions that impact their community's health and environment. This activity highlights the complexities of achieving social equity in resource distribution and environmental benefits.

Model United Nations on Water Equity

Students participate in a Model United Nations-style debate focusing on global water equity issues. They represent different countries, with a focus on the disparities between water-rich and water-poor nations, including discussions on international aid, technology transfer, and strategies to ensure equitable access to water resources.

Debate: Balancing Economic Development and Environmental Equity

Students engage in structured debates on topics such as the impact of industrial development on water resources, the role of government in regulating access to clean water, and the responsibility of businesses towards ensuring environmental equity. This activity encourages critical thinking and understanding of different perspectives.

Documentary Making on Water Equity Stories

Students create short documentaries or digital stories that explore water equity issues within their own communities. They can interview local stakeholders, conduct research, and use multimedia elements to tell compelling stories about the challenges and solutions related to equitable water access.

"A Day Without Water" Challenge

An activity where students must journal every time they use water, to reflect on the importance of water in daily life and understand the challenges faced by those without reliable access to clean water. This experience is followed by a reflection session where students share insights and discuss ways to support water equity.

Water pollution

Water pollution is something that is sometimes obvious: think of plastic bags floating in a river or an oil slick spreading out across a lake. However, perhaps more dangerously, pollution can also be invisible: think of chemicals being released from industrial sites into rivers and streams.

There is a great deal of credible and detailed information already available on the internet and there is little point in trying to replicate that here. This article will provide an overview of water pollution and some related issues. More information is available via the references if you choose to dive deeper into the topic.

How is water pollution defined?

As defined by Encyclopaedia Britannica, "pollution" is defined as "the addition of any substance … energy … to the environment at a rate faster than it can be dispersed, diluted, decomposed, recycled or stored in some harmless form [215]. "Water pollution" is, obviously, more narrowly defined as the release of substances or energy into a water body at a rate that the release "interfere[s] with beneficial use of the water or with natural functioning of ecosystems" [216].

Where does it come from?

Pollution is often thought of as anthropogenic (i.e. human caused) but, technically, pollutants can also come from natural sources such as minerals leaching from the ground through which the water travels [217].

Pollution is also classified into "point source" and "non-point source". As the terms suggest, point source pollution is used when the source is a single identifiable source such as a factory. Non-point source pollution, on the other hand, is pollution which

215 Encyclopaedia Brittanica, 2024, Pollution. https://www.britannica.com/science/pollution-environment. Accessed 2024-06-03.

216 Encyclopaedia Brittanica, 2024, Water pollution. https://www.britannica.com/science/water-pollution. Accessed 2024-06-03.

217 Khatri, N. and Tyagi, S., 2014, Influences of natural and anthropogenic factors on surface and groundwater quality in rural and urban areas. https://doi.org/10.1080/21553769.2014.933716. Accessed 2024-06-04.

cannot be pinned to a single source and arises from a large area such as urban run-off [218] or airborne pollutants falling from the air.

What are the effects of water pollution on communities?

Health Hazards

Pollutants such as heavy metals [219], chemicals , and pathogens (e.g. blue-green algae) can contaminate drinking water sources. Drinking polluted water may lead to diseases such as cholera, dysentery, and other gastrointestinal issues. A 2022 report estimates that water pollution is responsible for 1.4 million deaths annually [220]. More broadly, it is estimated that over 2.2 billion people globally do not have access to safely managed drinking water [221].

Recreational use of polluted water (e.g. swimming) can also lead to illnesses such as skin rashes, respiratory infections, and other illnesses. Advisories about blue-green algae, for example, warn people to avoid all contact with the water and note that boiling water from water polluted with blue-green algae will not remove the toxins [222].

Economic effects

Medical costs

Waterborne diseases from pollution can lead to higher healthcare costs for individuals and governments. Treating such illnesses can impose significant financial burdens on communities, especially in Lower and Middle Income Countries

218 Kuzniewski, S., 2023, What is point source pollution? https://www.wwdmag.com/what-is-articles/article/33010576/what-is-point-source-pollution. Accessed 2024-06-04.

219 Government of Canada, 2023, Releases of harmful substances to water. https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/releases-harmful-substances-water.html. Accessed 2024-06-04.

220 Fuller, R, Landrigan, P.J, et al, 2022, Pollution and health: a progress update. https://www.thelancet.com/journals/lanplh/article/PIIS2542-5196(22)00090-0/fulltext. Accessed 2024-06-04.

221 UNICEF, 2024, Progress on Household Drinking Water, Sanitation And Hygiene 2000-2022. https://www.unicef.org/wca/media/9161/file/jmp-2023-wash-households-launch-version.pdf. Accessed 2024-06-04.

222 Alberta Health Services, 2024, Cyanobacteria (blue-green algae) advisory issued for Skeleton Lake. https://www.albertahealthservices.ca/news/Page18261.aspx. Accessed 2024-06-04.

which often lack water treatment capacity [223] and may also offer limited access to healthcare [224].

Loss of income

Communities relying on fishing or tourism can suffer economically as polluted waters deplete fish stocks and deter tourists (e.g. Antigua & Barbuda [225]). Such losses can result directly from costs such as repairing pollution-caused damage to equipment or reduced earnings because tourists are deterred from visiting polluted areas. There may also be related indirect costs such as the costs of cleaning up the pollution or lost investment opportunities.

Social disruption

Decreased food security

Pollutants can accumulate in and on fish and crops irrigated with polluted water, posing health risks to consumers (e.g. "blue baby syndrome" in infants from nitrates and organophosphate accumulation [226]). Further, contaminated irrigation water can lower crop yields and affect food security [227], particularly in agricultural communities.

Community displacement

Communities may be forced to relocate due to water pollution, especially if their water sources become unusable for consumption or growing the foodstuffs they need. For example, saltwater intrusion is believed to be driving population migration

223 United Nations, 2023, The United Nations World Water Development Report 2023: Partnerships and Cooperation for Water. https://www.unesco.org/reports/wwdr/2023/en/home. Accessed 2024-06-25.

224 Olufadewa, I, Adesina, M and Ayorinde, T., 2021, Global health in low-income and middle-income countries: a framework for action. https://doi.org/10.1016/S2214-109X(21)00143-1. Accessed 2024-06-25.

225 Mittempergher, D, Raes L and Jain, A, 2022, The economic impact of marine plastic pollution in Antigua and Barbuda: Impacts on the fisheries and tourism sectors, and the benefits of reducing mismanaged waste. https://www.iucn.org/sites/default/files/2023-01/plastic-waste-free-islands-caribbean-economic-assessments-3-compressed.pdf. Accessed 2024-06-10.

226 FAO, 2017, Water pollution from agriculture: a global review - Executive summary. https://openknowledge.fao.org/items/313b740f-583e-43ba-a36c-5e8c66236ca9. Accessed 2024-06-11.

227 Thompson, L.A. and Darwish, W.S., 2019, Environmental Chemical Contaminants in Food: Review of a Global Problem.

in areas of Mexico and Bangladesh [228] while there is rising concern in island nations over water supply in the face of rising sea levels [229].

Social strain

Polluted water can, in effect, result in less safe-to-use water being available. The resulting scarcity can worsen social tensions and inequalities within communities. The issues can range from different parts of the community having different levels of access to safe and secure drinking water to competing priorities for the use of the water. For example, industrial and agricultural users may be competing for the same water, or people in established suburbs with functioning water distribution systems may have better and/or cheaper access to potable water than people in informal settlements reliant on, say, bottled or untreated water [230].

What are the effects of water pollution on the environment?

There is a great deal of published material on the ecological effects of water pollution. What follows is a high-level summary of some key issues.

Biodiversity Loss

Pollutants can be toxic to aquatic organisms, leading to reduced populations and biodiversity. Heavy metals, chemicals, and plastic debris can be particularly harmful. Pollution can degrade habitats such as coral reefs, wetlands, and mangroves, which are crucial for many species' survival.

228 Xu, L and Famiglietti, J, 2023, People move where water flows: global patterns of water-driven human migration. https://www.globalwaterforum.org/2023/06/29/people-move-where-water-flows-global-patterns-of-water-driven-human-migration/. Accessed 2024-06-11.

229 United States Geological Survey, 2018, Many Low-Lying Atoll Islands Will Be Uninhabitable by Mid-21st Century. https://www.usgs.gov/news/national-news-release/many-low-lying-atoll-islands-will-be-uninhabitable-mid-21st-century. Accessed 2024-06-25.

230 Calverley, C.M and Walther, S.C, 2022, Drought, water management, and social equity: Analyzing Cape Town, South Africa's water crisis. https://www.frontiersin.org/journals/water/articles/10.3389/frwa.2022.910149/full#h7. Accessed 2024-06-18.

Eutrophication

Excess nutrients, particularly nitrogen and phosphorus, can lead to algal blooms, which deplete oxygen in the water, causing dead zones where aquatic life cannot survive. See 'eutrophication' for more information.

Bioaccumulation and Biomagnification

The terms refer to the accumulation of pollutants in the food chain but mean different things. "Bioaccumulation" refers to the accumulation of substances in a specific organism as it lives and feeds in the environment. "Biomagnification", on the other hand, refers specifically to the increasing concentration of the substance in the organisms higher up the food chain as they eat organisms lower down the food chain [231]. A classic example of this is the biomagnification of DDT, an insecticide which started being used in the 1940s [232]. Several decades later, DDT was widely banned due to its toxic effects higher up the food chain.

The bioaccumulation and biomagnification of pollutants in the food chain can threaten the health of organisms in the food chain and may, ultimately, pose health threats to humans.

Altered Ecosystem Functioning

Pollution can alter the chemical composition of water, affecting processes such as nutrient cycling and energy flow within ecosystems or simply killing the aquatic life (e.g. a Romanian tailings pond collapse is thought to have killed 1200 tonnes of fish). These ecological effects can arise from both short-term (i.e. "acute toxicity") or long-term (i.e. "chronic toxicity) presence of the pollutants [233]. However, lack of knowledge may make it difficult to connect the observed effects on the ecosystem to a specific pollutant.

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231 ScienceStuck, n.d., Difference Between Bioaccumulation and Biomagnification. https://sciencestruck.com/difference-between-bioaccumulation-biomagnification. Accessed 2024-06-19.

232 Center for Sustainable Nanotechnology, 2013, The Cautionary Tale of DDT – Biomagnification, Bioaccumulation, and Research Motivation. https://sustainable-nano.com/2013/12/17/the-cautionary-tale-of-ddt-biomagnification-bioaccumulation-and-research-motivation/. Accessed 2024-06-19.

233 European Environment Agency, 2018, Chemicals in European waters: knowledge developments. https://www.eea.europa.eu/publications/chemicals-in-european-waters. Accessed 2024-06-20.

Pollution can also degrade the quality of the aquatic ecosystem to the point that it is no longer safe to consume products such as fish (e.g. the methylmercury contamination issue in Grassy Narrows, Canada [234]) and such pollution may last for decades.

What can be done to reduce water pollution?

The options for dealing with pollutions can be loosely grouped into measures aimed at preventing pollution in the first place and measures intended to address pollution once it is in the water. Some measures may work to both prevent the pollution and also reduce existing contamination.

Preventive Measures

Proper waste disposal

Proper recycling and proper disposal of waste will prevent litter and pollutants from entering water bodies. This can be done through programs to manage solid and hazardous waste to prevent it from entering waterways. Implementing policies to support recycling programs, promote activities such as composting, and the provision of disposal facilities for hazardous materials will all help.

Pollution-aware agricultural practices

Implementing sustainable farming practices such as crop rotation, reduced use of pesticides and fertilizers, and the use of organic alternatives can reduce the amount of contaminants which can be washed off the land into water bodies. Further, using "buffer strips" along waterways will help to absorb excess nutrients and reduce runoff. Helping local farmers to adopt sustainable agricultural practices can reduce soil erosion, runoff, and chemical use. Such practices include cover cropping and crop rotation.

Stormwater management

Implementing green infrastructure measures such as rain gardens, permeable pavements, retention ponds, green roofs and vegetated swales will help capture and filter urban stormwater runoff before it enters waterways.

234 Mosa, A, and Duffin, J., 2017, The interwoven history of mercury poisoning in Ontario and Japan. https://doi.org/10.1503/cmaj.160943. Accessed 2024-06-20.

Industrial Regulations which are monitored and enforced

Effective regulations on industrial discharges can provide guidance and minimum requirements to ensure that factories and plants treat wastewater before releasing it into the environment. However, those subject to such regulations need regular monitoring to enforce compliance with the specified environmental standards.

Remediation Measures

Once the contaminants are in or on the water, the focus needs to turn to remediation. Sometimes, however, the remediation implemented is simply dilution in which the concentration of a pollutant is lowered to levels which are no longer considered to be a concern or can be addressed through natural processes (e.g. Victoria, BC, sewage treatment until 2020 [235]). This is the source of the saying "The solution to pollution is dilution".

However, this approach does not always solve the problem. In some cases, especially in the case of non-soluble pollutants, the "dilution" may simply move the pollutant downstream which may negatively affect or cause concern among downstream users. In other cases, the "safe level" of the contaminant is unknown or a matter of disagreement. Lead, for example, in the United States is now considered to have no safe level in drinking water [236]. However, Canada permits a low level of lead in drinking water [237]. Further, as technology and science has advanced, there is a growing awareness of the potential negative effects of chemicals. These "Contaminants Of Emerging Concern" typically have not yet been sufficiently studied for a clear understanding of their effects and risk thresholds [238]. Thus, the effects of "dilution" are not well understood, and the approach may not be as effective as hoped.

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235 CBC, 2021, Victoria no longer flushes raw sewage into ocean after area opens treatment plant. https://www.cbc.ca/news/canada/british-columbia/victoria-sewage-plant-1.5867582. Accessed 2024-06-19.

236 United States Environmental Protection Agency, 2024, Basic Information about Lead in Drinking Water. https://www.epa.gov/ground-water-and-drinking-water/basic-information-about-lead-drinking-water. Accessed 2024-06-18.

237 Government of Canada, 2016, Water Talk - Lead in drinking water. https://www.canada.ca/en/health-canada/services/environmental-workplace-health/reports-publications/water-quality/water-talk-minimizing-exposure-lead-drinking-water-distribution-systems.html. Accessed 2024-06-18.

238 United States Geological Survey, 2019, Emerging Contaminants. https://www.usgs.gov/mission-areas/water-resources/science/emerging-contaminants. Accessed 2024-06-18.

Wastewater treatment

Treatment plants can remove a wide range of pollutants, including chemicals, heavy metals, and pathogens. However, they require significant resources (finance, scientific knowledge, operating skills, personnel) to build, operate and maintain. Not all communities, especially smaller communities, are able to find or dedicate the necessary resources. The lack of resources is a widespread problem: on a global level, 3.4 billion people "lacked safely managed sanitation services" in 2022 [239]. Here in Canada, an estimated 219 million cubic metres of municipal wastewater was released with no treatment in 2020 [240].

Community cleanup

Communities can work to reduce pollution by organising regular clean-up events along rivers, streams, beaches, and other water bodies to remove litter and debris and prevent them from entering the water. This type of activity also helps to raise awareness of the effects of water pollution and may encourage lower household pollution.

Restoring or creating natural clean-up areas

Restoring natural wetlands or creating new wetlands (e.g. Lost Lagoon wetland in Vancouver [241]), especially in urban areas, takes advantage of their natural filtration capabilities. Such areas also provide other ecosystem services [242] such as habitat for wildlife and green spaces which can enhance the "livability" of the urban environment for both the community and other species. Similarly, other green infrastructure such as bioswales or rain gardens can help mitigate urban pollutants [243].

239 United Nations Children's Fund, 2023, Progress on household drinking water, sanitation and hygiene 2000–2022: special focus on gender. https://data.unicef.org/resources/jmp-report-2023/. Accessed 2024-06-19.

240 Statistics Canada, 2023, Municipal wastewater treatment. https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/municipal-wastewater-treatment.html. Accessed 2024-06-19.

241 Kerr Wood Leidl, n.d., Stanley Park Stormwater Treatment Wetland. https://www.kwl.ca/project/stanley-park-stormwater-treatment-wetland/. Accessed 2024-06-19.

242 UN Environment Program, n.d., Ecosystem services. https://www.cbd.int/undb/media/factsheets/undb-factsheet-ecoserv-en.pdf. Accessed 2024-06-19.

243 Cossin, A,, 2024, What is a bioswale? https://www.stormwater.com/stormwater-management/sewers-drainage-systems/article/55019691/what-is-a-bioswale. Accessed 2024-06-19.

Educational and Policy Measures

As with many other human-caused issues, there are the usual social measures which can be implemented.

Public education and community involvement

Public awareness campaigns can be used to educate residents about the sources and effects of water pollution and ways to prevent it. At the school level, environmental education programs can teach children about the importance of water quality and pollution prevention. Involving community members, local businesses, and other stakeholders in water management decisions and initiatives will lead to greater participation in solving problems. Similarly, encouraging citizen science projects where community members can monitor local water quality and report pollution incidents will help

Policy and legislation

Policies and regulations aimed at protecting water quality, such as limits on pollutant discharges and penalties for violations can be developed. Their effectiveness is likely to depend on how ambitious the targets are and how effectively the policies and regulations are enforced. It may be possible to provide incentives for businesses and individuals to adopt pollution-reducing practices.

Integrating water management into urban planning to ensure that new developments include sustainable water use and pollution prevention measures will also help.

Conclusion

As we said at the beginning, there is a lot of material available on water pollution, its causes, and its effects. Polluted water is a global problem whose importance growing because of:

- Increasing global demand for freshwater (~1% per year);
- Increasing development leading to more sources and types of contaminants;

- Growing understanding of the health and economic effects of water contamination [244].

Call to Action

While there is much pollution that is out of our individual hands, it is important that we do what we can on an individual level to reduce the pollution that we individually may cause.

We can also work with others to clean up existing pollution and support community efforts to push for stronger anti-pollution laws, regulation and enforcement.

Teaching Ideas

Promote awareness

- Discuss sources of pollution in daily life (e.g. littering, using pesticides and herbicides).
- Explore ways to reduce one's pollution footprint (e.g. use more sustainably produced products).
- Use educational games and apps that focus on water pollution and its effects to engage children in a fun and interactive way.
- Use recycled materials to create art projects that depict polluted vs. clean water environments, helping children visualize the difference.
- Hold discussions and debates on the causes and effects of water pollution, encouraging children to think critically and propose solutions.
- Show age-appropriate documentaries or videos that explain water pollution and its impact on the environment in an engaging way.
- Share or read age-appropriate stories or books that highlight the impact of water pollution on the environment and marine life.

Hands-On Experiments

- Conduct simple in-class experiments to show how pollutants affect water. For example, mix clean water with different substances like oil or dirt and observe the changes.

244 United Nations, 2024, World Water Development Report 2024: Water for Prosperity and Peace. https://www.unesco.org/reports/wwdr/en/2024/download?hub=2. Accessed 2024-06-25.

- Create up a miniature wetland in the class and observe what happens to the plants if the water is polluted with various contaminants.

Field Trips

- Organize visits to local water treatment plants, lakes, or rivers where children can see the importance of clean water and the consequences of pollution.
- Participate in community clean-up activities at local water bodies, teaching children the value of taking direct action to reduce pollution.

Water management infrastructure

Dams and other water infrastructure (see here for more discussion) are a broad class of projects that play vital roles in modern society, providing benefits ranging from hydroelectric power, flood control, water supply security and on to recreational services. These projects can be the classic "grey" infrastructure of dams but also the "green" infrastructure of nature-based solutions such as created wetlands. Some examples of such projects are listed below:

- Dams
- Berms, dykes, levees, embankments
- Drinking water distribution systems
- Sewer and waste-water treatment systems
- Bioswales, green-roofs, wetlands

The community and ecosystem pros and cons of such projects depend on the type of project, how it is implemented and the nature of the problem it is intended to address. There is no "one-size-fits-all" solution and there may be several ways to achieve a desired outcome. And, different stakeholder groups are likely to have strong and very different opinions on the merits or otherwise of a given project.

The following article is a high-level overview of some of the issues of such infrastructure-focussed water management approaches. We will also explore some of the challenges and opportunities in balancing development and conservation. This article will not address water distribution, water treatment or wastewater management.

The role of dams

Dams serve multiple roles, each critical to the development and maintenance of human societies. They provide essential services including holding water for domestic, agriculture and industrial use, generating hydroelectric power, and recreation. While dams serve multiple functions, their operation and design is optimised to prioritise a very small number of services as some services may conflict with others. For example, a flood-control dam needs the reservoir to be kept

relatively empty to preserve space to capture flood run off. On the other hand, a hydro-power dam works best when the reservoir is kept full to give the greatest possible pressure on the turbines and to cater for years of lower flows. It is not possible to optimally operate the same dam for both purposes simultaneously.

For example:

- The new Springbank Dam [245] upstream of Calgary on the Elbow River is a flood control structure and slightly unusual in that the reservoir is intended to remain dry unless a flood event is happening. It is not able to generate electricity.
- "Site C" [246], in British Columbia, is designed as a run-of-the-river hydro-power project and needs to keep the reservoir levels high. When operated for power generation, it will have limited flood control ability.
- The Ghost Dam [247], upstream of Calgary on the Bow River, is designed as a hydro-power dam. It is operated as such most of the year but, for a few months during the peak flood-risk period, the reservoir level is lowered to prioritise flood control over power generation [248].
- The St Mary Dam [249], Canada's largest irrigation dam, is designed and operated primarily as a water supply dam for irrigation but also generates power and provides recreation opportunities.

All these dams are (or, where still under construction, will be) central to regional development and growth and highlight the importance of water infrastructure in supporting modern societies.

245 Government of Alberta, n.d., Springbank Off-stream Reservoir. https://www.alberta.ca/springbank-off-stream-reservoir. Accessed 20247-03-15.

246 BC Hydro, n.d., Site C Clean Energy Project. https://www.bchydro.com/energy-in-bc/projects/site_c.html. Accessed 2024-03-15.

247 TransAlta, n.d., Ghost. https://transalta.com/about-us/our-operations/facilities/ghost/. Accessed 2024-03-15.

248 Government of Alberta, 2022, Bow River – TransAlta agreement : Alberta Environment and Parks and TransAlta five-year water services agreement extension. https://open.alberta.ca/publications/bow-river-transalta-agreement-fact-sheet. Accessed 2024-03-15.

249 APEGA, n.d., Irrigation Transforms Southern Alberta. https://discoverapega.ca/stories/irrigation-transforms-southern-alberta/. Accessed 2024-03-15.

Other water management infrastructure

As noted above, dams are only one type of water management infrastructure. Others include flood barriers such as berms (also called dykes/dikes/levees), diversion channels or channelised rivers. Such structures are designed to manage floods up to a certain size. If the flood exceeds that design size, the protection they offer is severely compromised.

On a small scale, "dugouts" are used on farms to store run-off for later use. They can also offer an environment favourable to plants and wildlife but need careful planning and management [250]. Similarly, the work of organisations such as Ducks Unlimited to restore wetlands can help to restore natural water bodies and improve water quality.

Communities and the socioeconomic impacts of dams

The construction of dams can have profound positive and negative socioeconomic effects on local communities. In a nutshell: it's complicated!

Positives

Dams may bring benefits such as flood control, groundwater recharge, recreation opportunities, electricity, and a more secure water supply for communities, agriculture, and industry. Developed water resource infrastructure tends to encourage economic growth and community prosperity by providing a reliable water supply [251]. However, the picture is complicated with research suggesting the size of the dam is linked to whether or not areas near to the dam benefit or not – larger dams tend to primarily economically benefit more distant populations [252].

250 Government of Alberta, n.d., Understanding Prairie Dugouts. https://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/agdex15866/$FILE/716_B01_module2.pdf. Accessed 2024-06-25.

251 United Nations, 2024, The United Nations World Water Development Report 2024: Water for Prosperity and Peace. https://www.unesco.org/reports/wwdr/en/2024. Accessed 2024-03-27.

252 Fa, P, Cho, M.S, et al, 2022, Recently constructed hydropower dams were associated with reduced economic production, population, and greenness in nearby areas. https://www.pnas.org/doi/10.1073/pnas.2108038119. Accessed 2024-03-21.

Negatives

- **Population displacement**
  Dams require space, and sometimes that space, is already occupied, especially if the dam requires a lot of space. Consequently, communities are displaced (e.g. 1.3 million people were moved to enable construction of the Three Gorges Dam [253]) and those displaced may struggle to adapt to the loss of their ancestral lands or to find new comparable land.
- **Cultural disruptions**
  The dam and reservoir may bury or submerge historical and cultural sites (e.g. submergence of historical sites [254]). The loss of these heritage sites may have profound long-term impacts on communities' culture and social practices.
- **Damaged social cohesion**
  Displaced populations may face challenges in adapting to new environments, accessing resources, and maintaining social cohesion. Further, downstream communities may experience changes in water availability, water quality, and sediment transport, affecting their livelihoods and well-being. Dams can also lead to loss of livelihoods (economic displacement) as previous means of earning a livelihood may no longer be possible (e.g. a farmer whose land has been flooded). These negative effects tend to disproportionately affect already-vulnerable communities in the neighbourhood of the dam [255].
- **Loss of human food sources**
  Dams block migrating fish which can cause the collapse of fisheries which provided economic and nutritional sustenance to communities dependent on those fisheries [256]. Another problem is that of naturally occurring methylmercury. This toxin can bio-accumulate (concentrate in organisms higher up the food chain) and then contaminates the wildlife in the reservoirs

253 Wee, S., 2012, Thousands being moved from China's Three Gorges – again. https://www.reuters.com/article/idUSBRE87L0ZX/. Accessed 2024-03-15.

254 Cox, S., 2016, 'Gone Forever': Archaeologist Warns Site C Threatens First Nations Historic Sites. https://thetyee.ca/News/2016/01/09/Site-C-Threatens-Historic-Sites/. Accessed 2024-03-15.

255 Mavhura, E., 2020, Dam-induced displacement and resettlement: Reflections from Tokwe-Mukorsi flood disaster, Zimbabwe. https://doi.org/10.1016/j.ijdrr.2019.101407. Accessed 2024-03-21.

256 Cafasso, S., 2020, Hydropower dams threaten fish habitats worldwide. https://sustainability.stanford.edu/news/hydropower-dams-threaten-fish-habitats-worldwide. Accessed 2024-03-21.

and downstream of the dams. This is an existing problem in Canada [257] and one that is expected to grow as new hydropower dams are commissioned [258].

- **Long-term costs**
  One of the long-term challenges with water management infrastructure is the maintenance budget. The structures require maintenance and, possibly, upgrades to continue to operate to the expected standard and that work costs money the protected communities may not be able to afford. Failure to do necessary maintenance may ultimately lead to unfortunate results (e.g. Sainte-Marthe-sur-le-Lac in Quebec [259], dykes in southern BC [260], [261]).

  A longer-term issue is the life-span of the structure. As mentioned above, structures are designed and built to deliver services at a certain level. Over time, those services may no longer be wanted or the level (e.g. flood protection) may no longer be adequate. The necessary upgrades to return the structure to the desired level of safety and service may be more expensive than simply removing them [262]. Of course, removing structures that have been in place a long time is likely to be contentious [263] especially if there has

257 Austen, I., 2016, Canada's Big Dams Produce Clean Energy, and High Levels of Mercury. https://espp.fas.harvard.edu/news/canada%E2%80%99s-big-dams-produce-clean-energy-and-high-levels-mercury. Accessed 2024-03-21.

258 Calder, R.S.D, Schartup, A.T., et al, 2016, Future Impacts of Hydroelectric Power Development on Methylmercury Exposures of Canadian Indigenous Communities. https://pubs.acs.org/doi/abs/10.1021/acs.est.6b04447. Accessed 2024-03-21.

259 Lowrie, M., 2023, Residents of Quebec town still struggle with aftermath of 2019 dike break, flooding. https://www.cbc.ca/news/canada/montreal/residents-sainte-marthe-struggle-flooding-1.6827357. Accessed 2024-03-28.

260 Parfitt, B., 2023, Failure to act means failing dikes. https://www.policynote.ca/dikesfoi/. Accessed 2024-03-28.

261 Owen, B., 2023, B.C. aware of dike problems before destructive flooding in 2021, documents show. https://vancouversun.com/news/local-news/b-c-aware-of-dike-problems-before-destructive-flooding-in-2021-documents-show. Accessed 2024-03-28.

262 Massachusetts Department of Fish and Game, Division of Ecological Restoration, 2015, Economic & Community Benefits from Stream Barrier Removal Projects in Massachusetts. https://extension.unh.edu/sites/default/files/migrated_unmanaged_files/Resource006641_Rep9683.pdf. Accessed 2024-03-28.

263 Baumhardt, A., 2023, Feds consider removing Snake River dams in leaked agreement with plaintiffs in lawsuit. https://washingtonstatestandard.com/2023/11/30/feds-consider-removing-snake-river-dams-in-leaked-agreement-with-plaintiffs-in-lawsuit/. Accessed 2024-03-28.

been significant development which relies on the presence of those structures [264].

Environmental and ecosystem effects of dams

Habitat alteration and loss

Dams alter natural river ecosystems in significant ways, with far-reaching consequences for biodiversity and ecosystem services. The fragmentation, or breaking up, of rivers by dams disrupts the natural flow regime, impedes sediment transport, and alters habitats [265]. These changes can degrade aquatic and riparian ecosystems, leading to the loss of species diversity, changes in species composition, and habitat degradation [266]. Additionally, dams can impede fish migration, disrupt nutrient cycling, and exacerbate water quality issues such as eutrophication and sedimentation. These environmental impacts have implications for ecosystem resilience, food security, and the provision of ecosystem services.

Water quality and flow

Altering the natural flow of water bodies can impact water quality by changing how sediment such as sand is moved by the flow of water and reducing the flow of nutrients. Stagnant or still water behind dykes can lead to lower oxygen levels, affecting fish and other aquatic life. Additionally, the disruption of natural flooding cycles, which replenish nutrients in floodplains, can impact the health of these ecosystems [267].

264 Donovan, M., 2020, Breaching tradition: Salt marshes replacing Nova Scotia's dikes. https://www.cbc.ca/news/canada/nova-scotia/nova-scotia-dikes-sea-walls-salt-marshes-1.5454709. Accessed 2024-04-03.

265 World Wildlife Fund, 2004, Rivers at Risk: Dams and the future of freshwater ecosystems. https://wwf.panda.org/wwf_news/?13716/Rivers-at-Risk-Dams-and-the-future-of-freshwater-ecosystems. Accessed 2024-03-21.

266 International Rivers, n.d., Environmental Impacts of Dams. https://archive.internationalrivers.org/environmental-impacts-of-dams. Accessed 2024-03-21.

267 González Macé, O., Steinauer, K., et al, 2016, Flood-Induced Changes in Soil Microbial Functions as Modified by Plant Diversity. https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0166349. Accessed 2024-04-03.

Greenhouse gases

An effect of dams which is not always appreciated is the potential for the reservoirs to emit carbon-dioxide and methane from the breakdown of plant matter. New research [268] suggests that, on a global scale, reservoirs are a significant source of these gases although the extent varies according to their proximity to the equator. Reservoirs in the tropics and subtropics produce more of the gasses than reservoirs in the higher latitudes. This is a particular concern as it is estimated that 65-75% of new hydropower reservoirs will be built in the topics and sub-tropics in coming decades.

"Safe" versus "Safer" or the infrastructure risk/protection paradox

A common reason for building a dam or a dyke is to provide community protection against flooding (e.g. the Springbank Dam referred to earlier). However, unfortunately, the construction of flood protection can result in *higher*, not lower, risk over time. Obviously, there is the new risk of dam or dyke failure (e.g. Derna dam failure [269], USA overview [270]) but properly-designed, properly-maintained and properly-operated infrastructure should not present a significant risk of failure.

Growth in risk from new development

However, the bigger issue comes from people's perception of being "safe". When we develop infrastructure to protect communities against flooding, a consequence becomes the building of new neighbourhoods and other developments in areas previously known as flood prone that are now seen as "safe" from floods. This means that while the probability of flooding may be reduced, the value of the houses and buildings as well as the number of people vulnerable to flooding increases if there was to be a failure of the water management infrastructure. This increases the risk of

268 Harrison, J.A., Prairie, Y.T., et al, 2021, Year-2020 Global Distribution and Pathways of Reservoir Methane and Carbon Dioxide Emissions According to the Greenhouse Gas From Reservoirs (G-res) Model. https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2020GB006888. Accessed 2024-03-21.

269 CNN, 2023, Aging dams and missed warnings: A lethal mix of factors caused Africa's deadliest flood disaster. https://www.cnn.com/2023/09/14/middleeast/lethal-factors-leading-to-libya-floods-intl/index.html. Accessed 2024-03-27.

270 Association of State Dam Safety Officials, n.d., Dam Failures and Incidents. https://damsafety.org/dam-failures. Accessed 2024-03-27.

damage occurred and increases the costs of actions like rehousing people affected in comparison to if the infrastructure hadn't been built (e.g. British Columbia's Sumas Prairie [271]). The core mistake is in thinking in absolute terms: that infrastructure makes one "safe". The truth is that infrastructure should make one "safer" but there is always a remaining level of risk. This is most easily seen with dykes: they are built and designed to manage storms up to a certain size. The protection they offer against a bigger-than-designed-for storm is greatly reduced as the water simply flows over the top of the dykes and, should the dykes fail, the failure may make the damage worse than if the dykes hadn't been there in the first place.

Growth in risk from climate change

Another source of "new" risk is the effects of a changing climate on storm frequency and intensity. A structure is designed to a "service level" of protection against extreme water events of a certain size. For example, a new structure might be designed to protect an area against, say, a storm with a 1:200 chance of happening. This means that a bigger storm, say 1:300, will not be protected against but the builders of the structure are prepared to accept the consequences of a storm that rare.

However, climate change is increasing both the intensity and the frequency of severe storms. Which means, in effect, that a storm in Canada which currently occurs with a 1:50

A (very brief) description of RCP scenarios

"Representative Concentration Pathways" (RCPs) are climate change scenarios which have been adopted globally to project future greenhouse gas concentrations. These "pathways" describe future greenhouse gas (GHG) (e.g. Carbon-dioxide) concentrations and are used to make predictions of our future climate at various dates in the future. RCP 8.5 is the most extreme (i.e. most GHG) scenario and assumes that the world's GHG emissions will continue to increase in the 2000's. See here for more information.

271 CBC, 2021, Before-and-after satellite images show flood devastation in B.C.'s Sumas Prairie. https://www.cbc.ca/news/canada/british-columbia/bc-floods-sumas-prairie-before-after-images-1.6258803. Accessed 2024-03-27.

frequency is expected to become a 1:10 event by the late 2000's [272] under the RCP8.5 emissions scenario.

The result of this is that, over time, the "service level" protection provided by the new structures declines. And that communities who had thought they were protected against a, say, 1:50 event will only have a fraction of that protection.

Use caution and think carefully

Dams and dykes are vitally important tools in community protection against flooding and dam reservoirs provide valuable water management capabilities. However, communities protected by such structures need to be cautious and deliberate about permitting further development in the protected areas.

Conclusion

Water management infrastructure can and does bring both benefits and costs to communities and ecosystems. Trying to balance those benefits and costs is not simple [273]. Communities need to involve all stakeholders in the necessary discussions to choose the most appropriate and long-term sustainable solution. Ensuring the resilience and health of both human and natural communities requires ongoing effort and collaboration by all stakeholders.

Call to Action

Have a look around your community and see how much water management infrastructure you can find.

- How much do you know about it?
- What does it do and how does it do it?
- Why was it built?
- Is any of it dedicated to flood control? To drought mitigation?

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272 Government of Canada, 2019, Canada's Changing Climate Report. https://changingclimate.ca/CCCR2019/. Accessed 2024-03-27.

273 Parshley, L., 2018, The Costs and Benefits of Hydropower. https://www.smithsonianmag.com/innovation/costs-and-benefits-hydropower-180967691/. Accessed 2024-03-28.

- Is it “grey” or “green” infrastructure?
- What size storm can it handle?
- Who manages it?

Potential education approaches to teaching about infrastructure

- Build a model dam or berm in a tank or on the ground and see how it behaves with differently sized “floods” from a bucket or a hose.
- If the school property or nearby property permits, study a local wetland. To take it further, undertake a wetland restoration project and study the effects of that on biodiversity.
- Site visits to local water management infrastructure such as a storm pond or dam with an expert to explain what is being seen.
- Site visit to reservoirs constructed for fish and wildlife habitat.
- Site visit to structures constructed and maintained for recreation and cultural purposes.

Water scarcity

Water scarcity is a term which is not well defined and means different things in different places and at different times. In general terms, "water scarcity", also known as "water shortage" and "drought", occurs when the demand for water in an area is greater than the available supply or when the water's poor quality restricts its use.

Note that "drought" has several definitions which we discuss here. Because of the many possible types of "drought", the longer "water scarcity" or "water shortage" terms tend to be used by water quantity specialists.

The mismatch of demand exceeding supply can result from both the supply side and the demand side.

- Supply side challenges can result from issues such as reduced precipitation (i.e. less rain/snow), loss of a water source (e.g. drying up of an aquifer) or pollution contaminating a water source.
- Demand side challenges can result from a growing population, increased agricultural and industrial demands, and inefficient water use (e.g. leaks from aging water distribution infrastructure).

Water shortages can lead to significant problems, such as health hazards, crop failure, food shortages, communal conflict over water use and reduced economic activity. This article will look at ways in which water scarcity can be addressed.

Changing water supply

Increasing the supply of water is usually very difficult or very expensive or both. So, if the supply cannot be easily increased, the only other option is to use the existing supply more efficiently. There are many proactive measures communities can take to improve their use of the available water.

Add water storage

As discussed above, a water shortage occurs when water demand exceeds supply. One approach then, is to add more storage in the cases where supply sometimes exceeds demand so that the "excess supply" (e.g. spring run-off) is preserved for later use in a drier period (e.g. late summer). This can happen in several ways:

Home rain storage

Installing rain-water barrels means that rain that would normally flow off the property is captured on the property and can be used on the property later. This approach has benefits beyond simply storing free water for later use. For example, capturing rainfall on the property will reduce the flows in community stormwater systems and can help reduce community flooding [274].

Storage dams

While "build a dam" seems to be an obvious answer to water shortage, like many things it is not that simple. We have much more content on dams here and in this collection but some initial issues to be considered are:

- Is there a space suitable for building a dam?
- Are the expected precipitation and river flows going to be sufficient to fill the reservoir now and in the future?
- How much water will the new reservoir lose to evaporation? What effect will the future warmer temperatures expected under climate change have on the evaporative loss of the dam?
- What will be the effect of the new reservoir on local and downstream communities and ecosystems?

Aquifer recharge

We have written more about Managed Aquifer Recharge in the Groundwater article in this collection but the basic point is that it may be possible to deliberately use aquifers to store water for later use. Whether this is a viable approach for any given community will depend on the local aquifers. Which, in turn, means that those aquifers need to be researched and well understood.

Treat more water

Most water requires some treatment to make it safe for human consumption. If there are available sources of non-potable water, it may be possible to treat that water. An extreme example of this is desalination for coastal communities. While this will produce potable water, that water comes at a very high energy cost. It is estimated

274 Government of Canada, 2022, Property protection. https://www.canada.ca/en/campaign/flood-ready/prepare-home/property-protection.html. Accessed 2024-04-04.

that desalination uses 26% of the world's total energy used in the water sector [275] (p.68). Aside from the energy cost of treatment, there is a significant financial cost which leads to something called the "water-prosperity paradox": while safe, accessible water and sanitation fosters prosperity, providing that safe, accessible water requires prosperity [276] (p.148). So, while it may be technically possible to improve and upgrade the water supply plants, the community may not be able to afford the upgrades, or the subsequent cost of the treated water, or have the skills to continue operating the treatment plants over the long term.

It must be noted that safe potable water is not universally accessible here in Canada nor in the rest of the world. For example, Canada had 28 long-term boil-water advisories in 26 First Nation reserve communities as of January 2024 [277]. Globally, in 2023 it was estimated that 26% of the global population did not have access to safe drinking water [278].

Reduce run-off, loss

We've written much more here about using "green infrastructure" to reduce run-off. However, the key point is that several benefits result from slowing down surface run-off and using things such as bioswales and wetlands:

- The rain water has more opportunity to penetrate into the ground and provide moisture to plant roots and to recharge aquifers for possible future use.
- As with property rain barrels, slowing down the run-off reduces the pressure on community stormwater systems and helps mitigate the smaller, more-frequent floods.
- Local ecosystems will benefit from the additional moisture which may in turn result in many benefits ranging from "cultural" (e.g. recreation) to

275 United Nations, 2024, The United Nations World Water Development Report 2024: Water for Prosperity and Peace. https://www.unwater.org/publications/un-world-water-development-report-2024. Accessed 2024-04-05.

276 United Nations, 2024, The United Nations World Water Development Report 2024: Water for Prosperity and Peace. https://www.unwater.org/publications/un-world-water-development-report-2024. Accessed 2024-04-05.

277 Government of Canada, 2024, Ending long-term drinking water advisories. https://sac-isc.gc.ca/eng/1506514143353/1533317130660. Accessed 2024-04-05.

278 UNESCO, 2024, Imminent risk of a global water crisis, warns the UN World Water Development Report 2023. https://www.unesco.org/en/articles/imminent-risk-global-water-crisis-warns-un-world-water-development-report-2023. Accessed 2024-04-13.

"maintenance" (e.g. water quality improvements, improved air quality) to "provisioning" (e.g. traditional medicinal resources, food supply) [279].

Addressing water scarcity involves improving water management practices, investing in infrastructure to treat and recycle water, and adopting policies that promote water conservation and sustainable use.

Changing water demand

If it is not always possible to increase the supply, it may be possible to reduce the demand for water. In extreme cases, this can be done through approaches such as water rationing but there are many other options, too.

Maintain and upgrade infrastructure

Encourage community members, businesses, and industries to reduce their demand through simple actions such as fixing leaks, using water-efficient appliances, and practicing maximally efficient irrigation techniques.

Leaks in water distribution systems can consume a startling percentage of the water being produced by treatment plants (e.g. Johannesburg, South Africa, is thought to leak 25% of the water passing through its distribution network [280] which is a significant factor in the frequent supply interruptions [281].)

Implement Water Conservation Measures

Irrigation agriculture can improve its water efficiency by changing the way it irrigates. Irrigators talk about "field application efficiency" which refers to the percentage of water applied in the field that is used effectively by the plants. The following table shows varying levels of "field application efficiency" for different irrigation methods.

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279 Elliot, R.M, Motzny, A.E, et al, 2020, Identifying linkages between urban green infrastructure and ecosystem services using an expert opinion methodology. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6965533/. Accessed 2024-04-10.

280 Sheridan, C., 2024, Johannesburg's water crisis is getting worse – expert explains why the taps keep running dry in South Africa's biggest city. https://theconversation.com/johannesburgs-water-crisis-is-getting-worse-expert-explains-why-the-taps-keep-running-dry-in-south-africas-biggest-city-223926. Accessed 2024-04-04.

281 Ntshangase, N., 2024, Taps have run dry across South Africa's largest city in an unprecedented water crisis. https://www.usnews.com/news/world/articles/2024-03-21/taps-have-run-dry-across-south-africas-largest-city-in-an-unprecedented-water-crisis. Accessed 2024-04-04.

Irrigation method	Field application efficiency
Surface irrigation (border, furrow, basin)	60%
Sprinkler irrigation	75%
Drip irrigation	90%

Source: Food & Agriculture Organization [282].

Changing to, say, "drip irrigation" from "surface irrigation" allows for the same amount of water to reach the plants' roots while overall reducing the amount of water that is needed for the crop. An alternative approach, of course, may be to change crops from crops requiring high volumes of water to crops requiring low volumes [283].

In urban areas, water restrictions are used to reduce daily per capita water consumption [284]. People may be encouraged to reduce their personal consumption through measures such as taking shorter showers, changing how they wash dishes, etc. Greater re-use or recycling of water can also be used to reduce water withdrawals and reduce demand.

Similarly, industry may be able to reduce its water consumption through changed practices and greater re-use of water. The concept of "water-use efficiency" [285] is defined as the ratio of dollar value added (i.e. how much additional value is produced from the water – think of an irrigated versus non-irrigated farmer's field) to the volume of water used. This provides an economic measure of how efficiently water is being used. The measure is one the indicators used to monitor progress on the United Nations' Sustainable Development Goal 6: Clean Water and Sanitation. Although the data set is based on 86 countries and is, therefore, not complete, in the

282 Bwower, C. Prins, K, and Heibloem, M., 1989, Irrigation Water Management: Irrigation Scheduling. Annex I: Irrigation efficiencies. https://www.fao.org/3/T7202E/t7202e08.htm. Accessed 2024-04-04.

283 Statistics Canada, 2021, Agricultural irrigation patterns in Canada from 2012 to 2018. https://www150.statcan.gc.ca/n1/pub/16-508-x/16-508-x2021001-eng.htm. Accessed 2024-04-04.

284 City of Calgary, 2024, Outdoor water restrictions. https://www.calgary.ca/content/dam/www/uep/water/documents/water-documents/outdoor-water-restrictions/outdoor-water-restrictions-summary-guide.pdf. Accessed 2024-04-04.

285 Food and Agricultural Organisation, n.d., SDG 6.4.1 Change In Water-Use Efficiency. https://www.unwater.org/sites/default/files/app/uploads/2022/03/SDG-641-Infographic_Introducing-water-use-efficiency_Dec-2021.pdf. Accessed 2024-05-22.

2015-2018 period, water-use efficiency increased 9% with a 15% increase in the industrial sector [286]. The increased efficiency is an encouraging sign of the potential for future water conservation.

Price incentives

One method of reducing demand is to use the price for water to impose costs on users of that water and so discourage inefficient or wasteful use of water. An argument is sometimes made that water should be free. While it is true that some water falls from the sky and is free, the treatment to ensure the water is safe to drink, storage and distribution of water comes with costs [287]. Water prices are generally subsidised and there are very few jurisdictions where the full economic and environmental cost of water is covered by its price ([288], p.22).

Access to water and sanitation is considered a human right [289]. Setting the price for water in a way which recognizes that right and does not exclude the poorest in society while also discouraging wasteful use of water can be challenging. There are various pricing structures and charges which can be implemented to achieve this. For example [290]:

- **Abstraction charges** are charges intended to cover, at least partially, the cost of extracting the water. Such charges are likely to be higher for groundwater than surface water.

286 Food and Agricultural Organisation, 2021, Progress on change in water-use efficiency: global status and acceleration needs for SDG indicator 6.4.1. https://www.unwater.org/sites/default/files/app/uploads/2021/08/SDG6_Indicator_Report_641_Progress-on-Water-Use-Efficiency_2021_ENGLISH_pages-1.pdf. Accessed 2024-05-22.

287 de Albuquerque, C., 2021, Here's why putting a price on safe water will ensure universal access to it. https://www.weforum.org/agenda/2021/08/heres-why-putting-a-price-on-clean-water-will-ensure-universal-access-to-it/. Accessed 2024-04-13.

288 Organisation for Economic Co-operation and Development, 2010, Pricing water resources and water and sanitation services. https://read.oecd-ilibrary.org/environment/pricing-water-resources-and-water-and-sanitation-services_9789264083608-en. Accessed 2024-04-11.

289 United Nations, n.d., Human Rights to Water and Sanitation. https://www.unwater.org/water-facts/human-rights-water-and-sanitation. Accessed 2024-04-11.

290 Organisation for Economic Co-operation and Development, 2010, Pricing water resources and water and sanitation services. https://read.oecd-ilibrary.org/environment/pricing-water-resources-and-water-and-sanitation-services_9789264083608-en. Accessed 2024-04-11.

- **Pollution charges** can be attached to disposal of the water after use and can be imposed in various ways such as for the nature of the pollutant, the volume of the effluent and the destination of the discharge.
- **Wastewater charges** are increasingly being levied as a separate charge on the end user.
- **Tariff charges** are the costs per given volume of water. One approach is "block pricing" in which the price per, say, cubic metre of water ($/m^3), varies according to the total volume used. "Ascending blocks" means the $/m^3 increases as consumption increases and passes specified total volume thresholds [291]. One possible downside of such an approach is that large families may end up paying more per person than small families. "Descending blocks" has the price trend reversed where increased consumption results in lower $/m^3 rates (e.g. Toronto water rates [292]).

Remove thirsty invasive species

Native plants are adapted to the local conditions but, in some areas, non-native species have been introduced which require more water than the indigenous plants. Removing such plants and restoring the indigenous vegetation can support reduce water demand (by up to 16% in one source) and support water conservation efforts [293] (p.12).

Switch to less thirsty crops

Similarly to the concept above, it may be possible for agriculture to switch to crops requiring less water. For example, recent studies suggest that switching to lower water intensity crop types in California's Central Valley could reduce consumption by up to 93% [294]. Such switching may, of course, come with other challenges such as reduced profitability for the farmer.

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291 Ricato, M., n.d., Water Pricing - Increasing Block Tariffs. https://sswm.info/water-nutrient-cycle/water-use/softwares/economic-tools/water-pricing---increasing-block-tariffs. Accessed 2024-04-11.

292 City of Toronto, n.d., Water Rates & Fees. https://www.toronto.ca/services-payments/property-taxes-utilities/utility-bill/water-rates-fees/. Accessed 2024-04-11.

293 World Wildlife Fund South Africa, 2016, Water: Facts & Futures. http://awsassets.wwf.org.za/downloads/wwf009_waterfactsandfutures_report_web__lowres_.pdf. Accessed 2024-04-10.

294 Boser, A., Caylor, K, et al, 2024, Field-scale crop water consumption estimates reveal potential water savings in California agriculture. https://doi.org/10.1038/s41467-024-46031-2. Accessed 2024-05-22.

Collaborative and Integrated Water Management

Water is a limited resource, with many stakeholders, including the environment and ecosystem. If a water shortage is to be managed effectively, there needs to be collaboration among stakeholders, including government agencies, local communities, industries, and environmental organizations, to develop integrated water resource management plans that balance human needs with ecosystem protection [295], [296]. This is a process that requires a lot of time, genuine commitment from the participants and, ideally, mutual trust built on successful, meaningful cooperation.

Community Education and Awareness Programs

It is important to educate community members and industry about the importance of water conservation and ecosystem protection. Awareness campaigns (e.g. Calgary's 2024 drought planning) can encourage water-saving behaviours and support for conservation policies while also raising awareness of the issue [297].

Ecosystem implications

Ecosystems evolve and adapt to the typically prevailing conditions. If those conditions abruptly change, there are likely to be significant ecosystem challenges. Water shortage is likely to have the following consequences:

Habitat Loss and fragmentation

Reduced water availability can lead to the drying up of wetlands, rivers, and streams, resulting in the loss of crucial habitats for aquatic and terrestrial species. Low water levels and altered flow patterns can disrupt aquatic ecosystems [298], leading to

295 St-Jacques, M-C., 2009, A Framework for Developing Community Water Strategies. https://www.mcgill.ca/cariwin/files/cariwin/cws_framework.pdf. Accessed 2024-05-27.

296 United Nations, 2023, The United Nations World Water Development Report 2023: Partnerships and Cooperation for Water. https://unesdoc.unesco.org/ark:/48223/pf0000384655. Accessed 2024-05-27.

297 Global Water Partnership, 2017, Raising public awareness (C8.02). https://www.gwp.org/en/learn/iwrm-toolbox/Management-Instruments/Promoting_Social_Change/Raising_public_awareness/. Accessed 2024-05-27.

298 Myers, B., n.d., Drought Impacts to Freshwater Ecosystems in the U.S. Caribbean. https://www.usgs.gov/programs/climate-adaptation-science-centers/drought-impacts-freshwater-ecosystems-us-caribbean. Accessed 2024-05-23.

changes in water temperature, dissolved oxygen levels, and nutrient concentrations, which can negatively impact aquatic life resulting in events such as fish kills [299].

Reduced water flow can create barriers to the migration of fish and other aquatic-dependant species, hindering their ability to reach spawning grounds and access essential habitats including migratory bird breeding and staging areas. Fragmentation of aquatic habitats due to decreased water availability can isolate populations of species, reducing genetic diversity and increasing the vulnerability of species to extinction [300].

Increased Competition for Resources

During water shortages, competition for limited water resources intensifies among different users, including humans, wildlife, and agriculture, leading to conflicts and potential ecological imbalance. Prolonged water shortages can result in the collapse of entire ecosystems, leading to cascading effects on dependent species and disrupting ecological processes essential for ecosystem functioning.

Conclusion

Water shortages are some of the most challenging natural crises to address. Life and many economic activities require water and so, when there is a shortage of water, urgent action is required. However, dealing with water shortages is not simple as it usually requires long-term planning, extensive consultation with the many stakeholders who will often have very varied perspectives and changes in practices. With water being so essential to so many life-supporting requirements, a drop in the normally available supply of water can start a cascade of life-altering changes in the environment and the economy.

299 Shen, N., 2024, Drought signs raise fears of another fish die-off in B.C. rivers. https://www.cbc.ca/news/canada/british-columbia/drought-risk-fish-die-off-1.7197525. Accessed 2024-05-23.

300 Wildlife Management Institute, 2021, The Role of Drought in Aquatic Systems. https://wildlifemanagement.institute/outdoor-news-bulletin/august-2021/role-drought-aquatic-systems. Accessed 2024-05-23.

Call to Action

- Become aware of where your water comes from.
  Is it coming from renewable sources (e.g. rivers) or groundwater?
- Become aware of the water you use.
  How much are you using? What are you using it for?
- Become aware of the water being used in your community.
  How is water being used in your community? Who/what is the biggest user?
- Become aware of the water that is being wasted.
  Are you, personally, wasting water? Is your community wasting water?
- Become aware of how waste water is managed.
  Where does the water go when you've finished with it? Is it treated before being released into the environment? Is any of it re-used?

Teaching Ideas

Water Conservation Experiments

Conduct simple experiments to show how much water is used in everyday activities, like brushing teeth or taking a shower, and compare it with the amount of water available in different parts of the world.

Water Usage Diary

Have children keep a diary of their water usage for a week. This can include tracking how much water they use for drinking, bathing, and other activities.

Rainwater Harvesting Project

Create a small rainwater harvesting system at home or school and show children how collected rainwater can be used for plants or other purposes.

Gardening Projects

Involve children in gardening projects that use water-efficient methods, such as drip irrigation or using drought-resistant plants.

- Simulate different irrigation methods (e.g. flood versus drip) to compare outcomes (plant growth) against the amount of water used.

Field Trips

Organize visits to local water treatment plants, reservoirs, or conservation areas to give children a firsthand look at how water is managed and conserved.

Community Clean-ups

Participate in or organize community clean-up events near rivers, lakes, or beaches to highlight the importance of keeping water sources clean.

Arts and Crafts Projects

Encourage children to create posters, drawings, or models that depict the importance of water conservation.

Classroom Discussions

Facilitate classroom discussions about the causes and effects of water scarcity and encourage children to share their ideas on how to conserve water.

Reflection Journals

Have students maintain reflection journals where they write about what they have learned about

Simulations and Virtual Tours

Use simulations (e.g. Aquation: The Freshwater Access Game | Smithsonian Science Education Center (si.edu)) and virtual tours to show the impact of water scarcity in different parts of the world and how technology can help in water management.