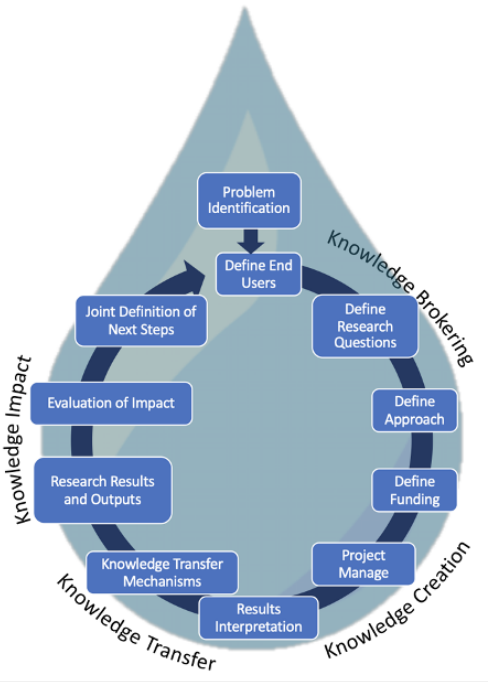
1. GWF's Knowledge Mobilization Approach

The Global Waters Futures (GWF) Program delivers state-of-the-art knowledge mobilization (KM) in conjunction with its scientific objectives of predicting change in cold regions, developing Big Data and support systems, and designing user solutions to focus on real world problems. KM is the process of moving knowledge from formal research projects into active use. It is an iterative and interactive process of sharing of knowledge between research producers and users including policy professionals, decision-makers and communities from beginning to end - during project development, research process and results interpretation and sharing. The most effective KM involves a close association of researchers and practitioners with co-creation intentions and methods. To support the KM goals of the program and the projects, GWF has established a KM Team through core financial support to partner institutions. The KM Core Team envisions a GWF legacy that has fostered innovation in researcher-practitioner co-creation that has led to policy advancements and positive social change for water science and management in Canada.

The GWF program was kicked off in 2016 with significant stakeholder engagement through a series of interviews with key individuals across Canada, in all water-related sectors including all levels of government, industries and non-profit organizations. The inaugural program Director and current program Director also visited and participated in discussions with Indigenous organizations and communities. Together, this engagement work framed the science objectives and the research and products needed by users, the development of an Indigenous co-led funding stream, and set the expectations for knowledge mobilization processes between GWF, partners, and potential users of the science and decision-support tools generated throughout the program.



GWF has achieved significant KM goals and milestones over the past three years. In part, this is due to the novel, program-wide and individual project approach to KM. Supported by the KM Core Team of representatives from each of the four partner institutions, network capacity building programming has been implemented that focuses on increasing awareness of KM, fostering researcher-practitioner relationships, building useful KM resources, and documenting the research impact of effective KM. Through a webinar series, workshops and presentations, the overall approach is to support all GWF projects to incorporate two-way engagement approaches into their research design and project delivery. Particular emphasis has been placed on training HQP through workshops to build KM planning, communication, plain language writing, and poster making, and other skills. The Team's KM logic model provides a roadmap for projects in co-creating and supporting research partnerships and guides the Team's capacity building services. This model describes how KM principles can lead to building larger research networks, both at the project and program level, that will leverage GWF resources to build new projects and research that will build on the legacy of GWF funding for years to come.

GWF projects have adopted many ways of engaging with their partners and users of research methods, results and products. These activities are key in maintaining the two-way interactive feedback needed throughout the research process. Many projects have implemented advisory committees, participatory working groups, and oversight teams composed of stakeholders that offer regular feedback and assist in co-developing annual meetings and gatherings to ensure agendas of interest. KM success is very dependent on building trusting personal relationships and researchers have built those byway of regular contact through phone calls, email exchanges, conference networking, and working meetings that inform each others' work that advance mutual needs. Projects host workshops dedicated to sharing results or to solicit feedback on certain products; they circulate regular newsletters and updates to keep their partners informed; and they respond to many requests to visit communities, present findings, and contribute their expertise to local or regional water resource management projects and issues; and much more. Below we offer more details on select examples of major KM activities of the project then the program.

2. Major KM Activities

a. Major Project-Level KM Activities: Events or activities hosted by individual GWF Projects that engage partners and user communities in co-development, iterative feedback and/or science/skills/tech transfer.

- Prairie Water hosts an Annual Partner's Meeting. Starting with a Kick Off meeting in 2017 to initiate the project and set mutual expectations and plans involving and impacting key stakeholders, and continuing in winter 2018 and 2019, each has grown in size of participants and depth of discussions with partners. Meetings have included sharing circles, presentations and panels of user perspectives, World Cafes and breakout discussions, and agenda content all co-developed between the project's operational manager and its Advisory Committee of partners. The annual meetings have fostered relationships and produced invaluable research direction and usability feedback for the project team. In 2019 the annual meeting was co-hosted by the Saskatchewan Association of Watersheds and featured an interactive Experimental Decision Laboratory where participants infused existing and new science generated by Prairie Water researchers into a scenario simulation to observe how users assess information and discuss types of evidence and make decisions under uncertainty using realistic water management challenges in the prairies.
- Integrated Lake Watershed Modelling for Policy and Decision Making (October 2019, Waterloo): Lake Futures held a workshop to bring together experts from US and Canada to provide guidance on the future of lake-watershed modelling. An outcomes report was produced and attendees requested follow up workshops to continue to discuss the sharing of ideas and techniques across end user organizations interested in improving their modelling to address water-related challenges.
- The eDNA for Healthy Watersheds project has hosted workshops to transfer new eDNA technology methods, protocols, tools and Standard Operating Procedures for students and researchers from several universities and agencies, particularly for fish monitoring.
- A workshop in Yellowknife co-organized by Northern Water Futures project, NASA ABoVE and the Government of Northwest Territories highlighted wildfire research results, policy, community impacts, and successes and needs moving forward. NWF PI Baltzer is the lead on

a fire research working group in which research on wildfire impacts is communicated regularly to GNWT managers.

- Ontario Phosphorus Research for Today's Farming (August 28th, 2019, London): Agricultural Water Futures jointly hosted a day-long event in southwestern Ontario with the Upper Thames Region Conservation Authority which included latest science presentations and on-farm site visits to demonstrate science in action and the outcomes of landscape interventions. The organizers targeted Certified Crop Advisors (CCAs) because they have a key role in advising farmers on nutrient management. Participation was capped at 56 attendees of which more than half (32 attendees) were CCAs with the remaining attendees from other partner and stakeholder groups. 100% of respondents rated the event 4 or 5 stars out of 5, with almost 94% of respondents indicating they learned something new and 97% of respondents indicating they would take their new knowledge back to farmers and/or colleagues.
- Wastewater managers meetings (ongoing, Waterloo Region) - The Linking Multiple Stressors to Adverse Ecological Responses Across Watersheds project team meets regularly with key wastewater managers in the Region of Waterloo (now on Zoom) to provide research results and advice on plant operations to reduce water quality impacts. They hold annual formal meetings where all directors, plant managers and senior water managers participate. The team provides a two-page summary of the work in advance and then students and researchers present research findings, followed by an open discussion and virtual coffee. Utilizing a meaningful co-creation approach, the partners are fully engaged in every step including the final publication of results. The project Co-I has mobilized this project's work through his appointment (2017-18) to the Canadian Water Network's national experts panel on Canada's Challenges and Opportunities to Address Contaminants in Wastewater and at the request of the federal government, the panel has met with senior leader at ECCC to discuss the their recommendations for a national plan of action. This panel has effectively raised the profile of wastewater nationally and has resulted in several initiatives (yet to be finalized).
- Northern Water Futures has partnered with Dehcho First Nations and Ka'a'gee Tu First Nation to support and deliver on-the-land camps in 2018 and 2019. The camps are an opportunity to engage youth in science, research and monitoring but also build traditional skills and spend time on the land. This results in enhanced understanding of the need to merge scientific environmental knowledge with traditional knowledge and inspire youth to become more involved in research and monitoring, and leaders of tomorrow. https://www.thesolutionsjournal.com/article/leading-land-science-camps-indigenous-youth-towards-reciprocity-research/

b. *Major Cross-Project KM Activities: Events that bring together multiple GWF projects with complimentary science objectives and similar user communities and stakeholders for sharing and discussions on integrating project methods and deliverables for leveraged impact.*

- The GWF inaugural Science Tour (February 11, 2020, Edmonton) was co-hosted by GWF and the Office of the Chief Scientist of Alberta Environment and Parks and brought together scientists working in regions and on water resources issues relevant to Alberta with approximately 80 professionals from provincial and federal government, industries, and community organizations. Successful breakout discussions resulted in post-event sharing of

government data to assist in modelling work, interest in Saskatchewan River Basin visualization and decision-support tools, and a science MOU between Alberta Environment and Parks and GWF was initiated.

- Grand River Conservation Authority (GRCA) Research Spotlight (October 9, 2019, Waterloo). GRCA is a key target of the science produced by GWF including potential to inform fisheries management, agricultural best practices, flood mitigation and protection of groundwater reserves. The Research Spotlight tagged onto an existing GRCA Water Managers meeting to enable practitioners to learn about the latest research happening in the Grand River watershed at University of Waterloo; strengthen relationships between researchers and water managers across the watershed; and allow researchers to learn from practitioners about the socio-economic political context within which they are conducting research. Attendees included GRCA staff, senior managers of municipal water, wastewater, and stormwater utilities, Six Nations and government water programs in the Grand River watershed. The workshop helped ensure knowledge produced through GWF and other projects is actively used to inform decision-making and transform the way local communities and governments prepare for and manage increasing water-related threats. The event was rated 4.6/5 with 100% of attendees saying they learned something new and 75% have valuable information to take back to their colleagues.
- The Agriculture-Water Research Expo (June 14, 2019, Saskatoon) was a joint initiative between Agriculture Water Futures, Prairie Water and Integrated Modelling Program for Canada. The event enabled researchers to learn from practitioners and build relationships with stakeholders. It included an interactive science 'expo' that included interactive modelling simulations, posters, a water quality smartphone beta testing application, drones, and hands-on water quality sampling; lightning talks from researchers; and roundtable discussions to promote two-way exchange of ideas between the 106 participants of which almost half (49 attendees) were from 33 partner or stakeholder organizations. The event had a high success rate and 89% of respondents rated the event 4 or 5 stars out of 5) with over 80% indicating they were likely to pursue further discussions.
- Several GWF projects (Northern Water Futures, Lake Water Futures and Global Water Citizenship) collaborated in organizing a water quality research and monitoring meeting that brought together researchers from around the country to support the vision of community-led monitoring initiatives. The Tsá TuéKe Kenahtsenehta Workshop was held on February 26-27, 2019 and facilitated a group of scientists and community residents to meet in Dél̨ı̨nę to develop a strategy for monitoring the ecosystem of Great Bear Lake. The workshop built on a series of earlier meetings which identified community and researcher priorities for the UNESCO international designated Tsá Tué Biosphere Reserve, the only Indigenous-led biosphere reserve in the world. The results of this workshop refine those priorities, identify key elements of an aquatic monitoring program for Great Bear Lake, and formulate a strategy for moving forward.
- Prairie Regional Indigenous Communities Gathering (January 8, 2018, Saskatoon) was held to continue the engagement and conversations with Indigenous communities and organizations that began with the program's initial consultation and existing research relationships. Seventeen individuals from 7 Saskatchewan First Nation communities and 2

organizations and 18 GWF researchers and advisors gathered for an afternoon and evening of sharing about water resources issues faced by Indigneous communities of the region, existing research being conducted with Indigenous communities, and identifying research needs that may be incorporated into the GWF program. This event was instrumental to building the GWF-hosted workshop in April, 2018 that brought community representatives and academics together to co-create the Indigenous Community Water Research Strategy and call for proposals and subsequently funded projects (see more below).

- Local Water Solutions Workshop (December 2018, Waterloo): Five projects at the University of Waterloo with a focus on nutrient management held a workshop with over 50 representatives from provincial and federal government, industry associations and NGOs. The objectives were to introduce new potential end users to the researchers, identify what stakeholders are interested in learning from this research, and provide an opportunity for students to present their work through infographic posters focusing on potential research applications. A follow up survey captured outcomes from the event: 88% ranked the event excellent or very good; the majority of practitioners (81%) said they will be having (or already had) further conversation with HQPs; and numerous researchers identified how input through the workshop changed aspects of their work including identifying new research questions to address current challenges faced by practitioners, incorporation of previously unknown data sources and adjustments to methodology.
- Prairie Modelling Workshops were (2017-2020) organized featuring work by Prairie Water, IMPC and the Core Modelling Team to develop robust participatory modelling tools for prairie basins. The interactive workshops presented the modelling tools and provided opportunities to 'play' with scenarios to receive feedback on applicability and usability. Participants discussed the water quality modelling responses to different beneficial management practices (BMPs) and decision-making trade offs with participants from Saskatchewan watershed groups, producer groups and government agencies. These ongoing workshops culminated in a hands-on modelling workshop in partnership with the Saskatchewan Water Security Agency (WSA) on January 27, 2020 in Saskatoon to provide experiential water quality modelling exercises to approximately 20 provincial scientists, project managers and other stakeholders. The WSA is now using the models to assess nutrient management scenarios to help them in water quality planning and management.

c. *Major Network-Level KM Activities: Events hosted or co-hosted by GWF to further the overall program's intended flagship outcomes and impact with key partners.*

- NRCan MOU Signing and Workshop (November 27, 2017, Ottawa): A direct outcome of discussions between GWF and NRCan at the GWF Inaugural Science Meeting in June 2018, a five-year Memorandum of Understanding (MOU) was signed to enhance collaborative research projects, personnel exchanges, and exchanges of scientific information and technical data to advance water research in critically important areas including climate change impacts on ecosystems, river basins, water bodies and natural resources development. NRCan committed to bringing its expertise in geology, forestry, mapping and Earth observation to the table and GWF network of scientists committed to bringing expertise in next-generation research tools that include artificial intelligence, drones,

satellites, and big data platforms to support and predict future water issues. A post signing workshop was held to identify specific areas of research to pursue collaboratively and to develop more specific joint project proposals.

- National Streamflow Forecasting Workshop (February 20-21, 2019, Vancouver): The first-ever National Flood Forecasting meeting was held to begin dialogue between the abilities and needs of provincial and private sector flood forecasting professionals in Canada, the capabilities of Environment and Climate Change Canada (ECCC) predication systems, and new and important research in the area of flood and hydrology forecasting by GWF and FloodNet. The two-day conference highlighted the various needs across the country for input information to inform decision-making and was considered instrumental in moving towards national coordination of streamflow forecasting and in advising ECCC and GWF. Participants in the meeting were invited to continue to act as an advisory user group for the GWF Core Modelling and Prediction Team.
- Water Security for Canadians Initiative (April 11, 2019, Ottawa): The Water Security for Canadians Initiative is a collaboration of scientists and policy experts who have come together to analyze Canada's emerging water crisis, and to chart a path forward to ensure water security for all Canadians. The Initiative leverages world class science and policy expertise to propose solutions that strengthen cooperative federalism in the context of water governance and management, with specific attention to enhancing the role of the federal government. The Initiative's inaugural event "Water Security for Canadians: Strategic Briefing and Discussion was held in Ottawa on April 11, 2019 and brought together 100 of Canada's top water and climate scientists, policy experts, legislators, and water decision rights holders and stakeholders. The discussion centred around a Concept Note developed by the Initiative partners, *"Water Security for Canadians: Solutions to Canada's Emerging Water Crisis."* The event began with opening remarks by the Honourable Ralph Goodale, then Canada's Minister of Public Safety and Emergency Preparedness and the Member of Parliament for Regina-Wascana and panelists spoke to the scientific evidence of the worsening water sustainability and climate-related water crisis in Canada, and the science and policy solutions needed to adapt to the new climate and water realities across the country. What resulted was a timely discussion on how to create a better, safer and more secure water world for ourselves and for our children, while positioning Canada as an international leader in global water security expertise, science, prediction and advice. Many of the proposed concepts became embedded in the election platforms of all parties leading up to the 2019 federal election and then the proposed concept of a Water Security Centre became a reality in the form of a mandate letter to the Ministers of Environment and Climate change and Agriculture and Agri Foods to develop a Canada Water Agency. GWF and Initiative partners became actively engaged in helping to support this agency's development, including a Whitepaper and set of recommendations for agency structure, function and mandate and in organizing a number of virtual events to engage the vast water community across the country in the agency's development (May-October 2020).
- Indigenous Community Water Research Strategy Co-development Workshop (April 17-18, 2018, Wanuskewin/Saskatoon): Approximately 60 GWF researchers and Indigenous community partners came together to build new, and enhance existing, Indigenous

community-university partnerships. The interactive workshop included discussions and working sessions focussed on building relationships, co-designing proposal elements and evaluation criteria, and identifying leveraging opportunities with potential funding partners. The primary outcomes of the workshop were the co-development of the Indigenous Community Water Research Strategy and a Request for Proposals (RFP) that included elements are more reflective of Indigenous values and processes, such as: Indigenous co-applicants; appropriate timelines and financial distribution; community engagement; consultation and agreements; data management that is sensitive to cultural use and sharing; integration of both Western and traditional knowledge generation; and direct community research benefits. As a result of the gathering the RPF was formally issued, GWF's Strategic Management Committee and an Indigenous Advisory Panel conducted a joint review of full proposals based on the evaluation criteria co-developed at the workshop and funding was awarded to 6 projects co-led between researchers and Indigenous community representatives. These projects now form the GWF Indigenous Community Water Research projects that are supporting community involvement, operating expenses, and the hiring of highly qualified personnel to address the unique and complex water issues of priority to Indigenous communities.

- GWF Annual Science Meetings co-hosted with Indigenous Communities: For the first time in Canada, the largest science gatherings (400+ people) were co-hosted on, and by, First Nation communities. As part of the Inaugural GWF Annual Science Meeting June 3-6, 2018, GWF scientists were invited to Six Nations of the Grand River, Ohsweken for a Climate and Water Summit to listen, learn, and share through food, music, cultural history and stories, and land-based knowledge exchange sessions. For many GWF researchers, this gathering was the first time visiting a First Nation community and was the beginning of new awareness and relationships. The GWF 2nd Annual Science Meeting was held May 14-17, 2019 was notable and unique for including significant science contributions from GWF supported Indigenous Community Water Research projects co-led between researchers and representatives from Indignoues communities across Canada, and a keynote from the Chief of the Federation of Sovereign Indigenous Nations, a Treaty and Inherent Rights organization that represents 74 First Nations, and over 160,000 Indigenous People in SK on water issues facing Indigenous Nations. The meeting also included a day-long Indigenous cultural sharing and learning exchange held at Wanuskewin Heritage Park. This involved local community Elders and members, Wanuskewin interpretive staff, and the Office of Indigenous Initiatives at USask, who shared knowledge of the history, culture, spirituality and worldview of the Indigenous Peoples of the region. Attendees learned about traditional dancing, drumming and Bison hide processing; toured archaeological excavations; and sampled Walleye, a traditional food for the Cree People in the Saskatchewan River Delta region. These meetings have been significant in building appreciation and skills in effectively recognizing the importance of research co-creation and Indigenous, traditional, and local knowledge as key to successful research projects and the GWF program.

3. Major KM Achievements including tools and products transferred to and used by partners and stakeholders

Citizen science apps and methods

- The Nutrient App was developed as a community, farmer and water manager focused nitrate and phosphate monitoring smartphone app that takes instantaneous nutrient measurements with an accuracy of <30% using inexpensive, commercially available test kits. Measurements are georeferenced and uploaded to a server and results visualized directly through the app or from a web browser for further analysis. Approximately 283 water quality observations have been made by about 30 users, and 10 individuals from watershed organizations and 10 community members of James Smith Cree Nation and Yellow Quill First Nation have been trained on the water sampling protocol and app use. An MOU with James Smith Cree Nation is currently in development to design and implement an environmental monitoring program for the community.
- Global Water Citizenship hosted a two-day workshop on mapping and GIS for students at Chief Jimmy Bruneau Regional High School in the community of Behchokǫ̀i n the Northwest Territories, in partnership with the Tłı̨chǫ Government. Students were taught basic GIS concepts, introduced to free and open source GIS software, and did some field-based GPS data collection and produced their own maps. The instructional materials were specifically developed for these students and their community, and they were provided with free copies of software for their own use.

Decision-Support Tools

- The Integrated Modelling Program for Canada has created a more accurate water management and allocation model for the Saskatchewan River Basin (MODSIM v.2) with a coupled irrigation demand model that enables the simulation of irrigation demand under a variety of future scenarios. The modelling effort is supported by a User-Centric Decision Support System - a prototype web application to visualize, interact with and communicate meaningfully with users. The decision support tool allows users to learn about the Nelson-Churchill basin system; access the models built to answer and explore questions for particular locations in the basin or water policy issues; view the mechanics of how the model calculates water information; browse about water issues in the basin; and collaborate with other users and interact with the basin. This platform has been key in engaging with majority-Indigenous residents of Cumberland House, an important partner to the IMPC program. Currently the visualization tool shows georeferenced photos and verbal clips from people who live in the Saskatchewan River Delta based on 40 hours of audio and video from interviews and time spent with 14 elder outfitters and land experts in the summer and fall of 2019, and a basic flood inundation map for different water levels. This work, and time spent in the Saskatchewan River Delta, enable the larger IMPC team to better understand how changes in flows impact Indigenous community values around the water, ecosystem and land. The web application has also been a key boundary object to show, engage with and discuss during major GWF meetings and workshops with other stakeholders in the Saskatchewan River Basin.
- Integrated Modelling Program for Canada's sensitivity and uncertainty analysis work has progressed to include several new additions to VARS-TOOL, a toolbox for comprehensive,

efficient, and robust model sensitivity and uncertainty analysis, including capabilities to handle non-uniform distributed input variables and correlated variables. The tool has been applied in several case studies by other GWF research teams and now has 350 users worldwide, including non academic users such as Agriculture and Agri-Food Canada, US Environmental Protection Agency, US Department of Agriculture, Goldwind (a Chinese wind turbine manufacturer), INTERA (US petroleum consulting firm), and others.

- Researchers with the Linking Stream Network Process Models to Robust Data Management Systems project developed a new patent-pending technology referred to as "Wobblestones". These specially designed stones are embedded with RFID technology that allows them to be tracked to within a few millimeters. They are being used by researchers and conservation authorities to understand how urban developments alter the course of streams and rivers. You can then input this data into models to test various land use intervention scenarios to determine which option has the least amount of ecological impact.
- Researchers with the Linking Stream Network Process Models to Robust Data Management Systems project developed the iEnvironment++ software platform to store and access data related to surface water. This innovative platform helps end users add data to the platform and use it to examine research issues as well as practical problems associated with surface water such as the impact of runoff on fish populations and on structures associated with water courses. It's success is demonstrated by the constant growth in new user groups, including research groups in Canadian Universities and NGOs as well multiple Ontario conservation authorities.
- Researchers with the Linking Stream Network Process Models to Robust Data Management Systems project also developed the Stream Power Index for Networks tool to use data that is already gathered by municipalities and conservation authorities to locate areas susceptible to erosion within urban river networks. Municipalities and conservation authorities such as the TRCA are the stakeholders that will most directly benefit from this tool. It can help improve erosion monitoring and guide development decisions by providing a way to see the impacts of different development plans to the erosion risk in the watershed. For example, the tool will help answer questions like "what happens to the erosion risk if we keep this area a greenspace?" or "what happens to the erosion risk in the watershed if we turn this area into a high-density residential area versus a low-density residential area?". The ability to answer these types of questions will give end users additional information to best decide future plans and to anticipate the effects of these plans. Other benefits include improved mitigation of flooding and erosion risk to private property and public infrastructure, with the potential to save millions of dollars.
- Science developed through Agricultural Water Futures is being incorporated into a farmer decision-support tool called "BOSS for Farms" (Best Optimization Scenario Selection). It is being developed by the Ontario Federation of Agriculture and Christian Farmers Federation of Ontario which together represent over 42,000 farms in the province. The tool will help farmers make better choices about which Best Management Practices (BMPs) to use on their farms. It allows farmers to more easily find the right combination of BMPs to suit individual field conditions and local environmental priorities. The developers of the

tool are working with Merrin Macrae to ensure the latest science and research is incorporated into their algorithms.

Model and Mapping Outputs

- The Prairie Water Project, in partnership with Agriculture and AgriFood Canada, has developed the first of its kind pesticide dataset and exposure risk model for the entire prairie agricultural region, providing new information regarding pesticide concentrations in wetlands at an extent not previously available. By identifying surface and subsurface water reserves at risk of environmental change, water managers and decision-makers can prioritize resource allocation and better mitigate future risk. The information is shared with AAFC, published within the Federated Research Data Repository and will soon be available for download by other interested stakeholders.
- The initial application of the THM model for risk assessment of buried water mains has been presented to the Cities of Toronto and Guelph through partnership meetings within a related NSERC Strategic project that GWF researchers have participated in. Various applications in NWT include the consideration of partially saturated flow and transport processes for more complete physical representation of soil water and contaminant movement in the shallow subsurface during freeze-thaw cycles, with a specific application within permafrost terrain (testing in Normal Wells)

Data Warehousing and Sharing Platforms

- GWFNet: Through a collaboration between the Data Management and Computer Science core teams, GeoNetwork has been created and deployed on a trial basis and evaluated (https://geonetwork-opensource.org/) as a platform for ingesting, managing, and displaying metadata related to data product outputs from across GWF. The adoption of this platform as the official metadata repository for GWF is now being considered.
- Cuizinart: Through a collaboration between the Data Management and Computer Science core teams, they have conceived, developed, and deployed the Cuizinart platform for "slicing and dicing" large environmental datasets. This addresses a common problem faced by researchers and practitioners in the hydrological sciences: it is difficult to manipulate data products that are often very large and encompass larger temporal and spatial domains than the user requires. For example, a researcher might only be interested in a few variables around Lake Erie during the winter of 2018, but the relevant source contains data spanning several decades across large swaths of the entire Great Lakes region. This scenario exemplifies what we refer to as the subsetting problem: typically, a researcher solves this by downloading the entire data product (or a large fraction thereof, depending on the collection's physical organization) and then manually extracting only the needed spatial and temporal domains. Needless to say, this is a slow and laborious process. The Cuizinart tackles this challenge by providing a Google Maps-like interface where researchers can request arbitrary subsets of data products, exactly matching the scenario described above. Users can choose from a list of data products, and then select the desired date range, variables, and spatial domain of interest. After this, users submit a request. Our backend service then processes the data product and extracts the desired subset, storing the results

in NetCDF files that follow the CF-1.6 standard. After this processing completes, the user receives an email with a download link where the data can be fetched.

- Northern Water Futures, Global Water Citizenship, Prairie Water projects have worked closely with the Gordon Foundation to upload community monitoring and academic research water quality data into existing DataStream, their data visioning products, to help expand the data fields offered through their web portal.

4. Examples of influence with stakeholders including to decisions, programs, policies

Federal Government

- In partnership with Environment and Climate Change Canada (ECCC), GWF has developed and is applying the Modélisation Environmentale Communautaire (MEC) – Surface and Hydrology (MESH) model over the major river basins across Canada. This work has significantly improved the model's representation of physical processes and human activities, such as glaciers, permafrost, mountains, lakes, reservoir operation and water withdrawals, and the ability to run the model under future climate and land cover scenarios to examine the range of possible water futures as part of a decision support system. This effort feeds into a key GWF goal to develop national water forecasting and prediction capability to enhance the varying levels of capacity, technology, data, and approaches among provinces and territories. A novel pilot project using MESH was launched in the Yukon River Basin, in partnership with ECCC and Environment Yukon, to provide streamflow forecasts and predictions for the Yukon River and its main tributaries. This has already led to increased capacity for flow forecasting during the spring and summer of 2020. This approach will be extended in the other major river basins in Canada, and then similarly in other cold regions of the world.
- Lake Futures developed a novel legacy model called ELEMeNT that can predict how long it will take for water quality improvement, given agricultural legacies accumulated due to decades of fertilizer application. First applied to the Grand River Watershed, it has now been applied to the Thames River Watershed, and the Sydenham River Watershed, with additional funding from ECCC. A phosphorus mass balance has also been developed for the Lake Erie Basin with county scale data, to improve understanding riverine concentrations of TP and SRP their response to changes across watersheds in the Lake Erie Basin. This work is being considered by the Adaptive Management Committee under Annex 4 of the Great Lakes Water Quality Agreement as the Governments of Canada and the U.S. determine how successful they have been at meeting a 40% phosphorus loading reduction goal for Lake Erie and how to improve the action plan moving forward.
- Spearheaded by the development of a 5-year isoscapes figure and its application to ongoing hydrological monitoring of lakes in the Peace-Athabasca Delta, NWF researcher (Wolfe) has developed a new collaboration with Parks Canada aimed at implementing use of water isotope tracers and other approaches to formalize a state-of-the-art Parks Canada–led aquatic ecosystem monitoring program for the Peace-Athabasca Delta. This is a significant knowledge translation achievement of our research program and will address science and

monitoring needs for the Peace-Athabasca Delta recognized by international (UNESCO) and national (Parks Canada) agencies.

Provincial/Territorial Governments

- The Agricultural Water Futures project has been consistently working alongside the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) through ongoing meetings and presentations to inform their policies and programs that promote the use of best management practices at the field scale to reduce nutrient loading to water bodies. In particular, OMAFRA is interested in AWF science on the impact of tile drains and drainage ditches on nutrient runoff; the cost-effectiveness analysis of BMP implementation and farmer decision-making related to BMPs. In the Prairies, AWF has developed extension materials for improving nutrient management
- The Linking Water Governance in Canada to Global Economic, Social and Political Drivers project developed and issued a delphi survey to identify external drivers of eutrophication in the Lake Erie basin, evaluating the extent to which they are accounted for in the existing governance system as well as the extent to which the governance system affects consideration of external drivers. Initial results indicate that the water governance community has been slow to recognize immigrant voices in research. This research could result in outcomes such as recommended strategies for enhancing participation of and gathering insights from New Canadians with respect to water management decisions (e.g., more equitable and representative water management structures and decisions).
- In partnership with the Water Quality Section of Alberta Agriculture and Forestry and then Alberta Irrigation Districts Association, the eDNA for Healthy Watersheds project has identified specific demands of users for assessment of irrigation waters, including harmful algae, effects of the herbicide Mag H, plankton communities and nutrient availability that was used to build a 2-year monitoring plan. The monitoring plan has been implemented, with eDNA methodology and tools customized to fit these needs, and data from the first year of monitoring has been generated and shared with the partners.
- The Integrated Modelling Program for Canada and GWF's Core Modelling effort has successfully introduced a modelling methodology that mimics the chaotic nature of river ice-jam formation to predict possible jamming and potential flooding. This modelling method has been refined and applied to river systems across Canada, including the Athabasca River at Fort McMurray, Alberta, Exploits River in Newfoundland and Labrador, and the Churchill River in Labrador, leading to the world's first operational ice-jam flood forecasting system which the Government of Newfoundland and Labrador has integrated into their standard protocol for flood forecasting. Manitoba Infrastructure is also now planning to operationalize this modelling tool which enables them to simulate ice-jams along the Red River in the short term using real-time data, and make long-term predictions using historical data. They are able to make ice-mitigation decisions within their ice cutting program, potentially saving a million dollars annually, and to protect citizens' safety and homes and save millions of dollars in the process. The work has also led to the publication of a user manual River Ice Processes and Ice Flood Forecasting: A Guide for Practitioners and Students.

Indigenous Communities and Organizations

Including Indigenous voices in water research and management in Canada is a necessary and ambitious goal. GWF has set out to achieve this goal through fostering best practices in Indigenous co-led and co-produced research and community engagement. GWF encourages the engagement and inclusion of Indigenous partners as part of all funded research activities. This is accomplished through different means by many of its projects, including: fostering engagement and participation in projects by Indigenous partners, creation of new partnerships, respectful sharing and co-learning of different knowledges, and co-created research outputs. The goal is to foster a greater appreciation and create a solid bridge between Indigenous and Western ways of knowing. Key activities and outcomes of GWF's Indigenous Community Engagement to date include:

- GWF's Indigenous Community Water Research Strategy was created to provide a clear pathway to ethical, co-creative, and synergistic research outcomes to address the unique water management challenges experienced by Indigenous communities.
- The Inaugural GWF Annual Science Meeting was co-hosted by Six Nations of the Grand River. This was the first time in Canada that a major science meeting was hosted by a First Nation. GWF scientists and partners were invited to Ohsweken to listen, learn, and share.
- A workshop in April 2018 at Wanuskewin Heritage Park in Saskatchewan focusing on "advice on what water research GWF and Indigenous communities can conduct together to help address the water issues experienced by Indigenous communities".
- Six Indigenous Co-led projects were funded by GWF that examine water quality, environmental monitoring and community well-being.
- With 39 GWF projects currently deployed and more on the way, with all core basins and observatories located on traditional Indigenous territories or reserve lands, GWF is developing best practices for ethical research strategies involving Indigenous communities, peoples, lands, and knowledge are essential to the success of GWF's projects. Some examples of project-level engagement and research with Indigenous communities include:
    - The Prairie Water Project co-designed with the First Nations community of Mistawasis Nêhiyawak, an Indigenous framework of collaborative water governance and development of flood risk maps for the community have been incorporated into their community climate action plan to address risk of future flooding.
    - The FORMBLOOM project conducted an environmental health scan with community members at lake and wetlands and discussed preferences for risk communications with counselors and community members.
    - The Integrated Modelling Program for Canada's researchers regularly attend meetings at the Northern Village of Cumberland House, SK, within North American's largest inland freshwater delta. Regular visits to the community have enabled presentations on progress, feedback and creative ways of communicating research back to the community. Collaborative efforts between the delta stewards, community ambassadors and researchers in computer science, water modelling, river ecology and and social science have led to the release of the pilot version of IMPC's User-Centric Decision Support System "UC-DSS" that was also debuted

at Cumberland House Delta Stewardship Committee meetings to gauge community interest for similar tools and feedback (see more about DSS below). IMPC's relationship with Cumberland House has also helped to expand network efforts in co-creating and sharing with Indigenous communities. Delta community residents co-presented with researchers at IMPC's virtual 3rd annual meeting that was attended by SaskPower and Saskatchewan Water Security Agency which opened up conversations between these organizations and community members with a level of engagement that had not always been possible before. The IMPC team intends on maintaining a consistent presence in facilitating conciliatory dialogues to help build stronger academic-community-industry relationships.

Industry

- The FORMBLOOM project has developed close and trusting working relationships with the operators of the Buffalo Pound Water Treatment Plant, providing critical science on the drivers of water quality problems affecting this water supply to 260,000 people in the Saskatchewan cities of Regina and Moose Jaw and surrounding areas. The partnership started from the deployment of a sophisticated water quality monitoring buoy which streams information to scientists and plant operators. These sensor-based measurements have been used to develop a bloom forecasting model and decision support criteria. The operators now have 'alarms' that identify in-lake conditions that can be problematic for treatment (e.g., low wind, large temperature variation, high biomass of algae or cyanobacteria) and allow modification of treatment processes. This has helped avoid incidents where bloom conditions and thermal stratification limit treatment capacity (as observed in 2015 and 2020, and periodically in different years). The science partnership has helped inform planning for infrastructure upgrades. Working together, researchers and plant operators have gained a better understanding of the seasonal dynamics of biological, chemical, and physical conditions in Buffalo Pound Lake, providing site-specific insights into cyanobacteria, toxin risk, and other factors affecting source water quality. These efforts are important for managing blooms locally. They also highlight how new technology can be applied to mitigate bloom risks across many bloom-affected surface waters in Canada, and provide new tools to manage and predict bloom risks.
- In partnership with NCAR, GWF is producing new high-resolution atmospheric data (CONUS II) that covers all of Canada that will be available for hydro-meteorological applications. The Weather Research and Forecasting modelling system has generated high resolution climate simulations for historical (2001–2015) and future (2086–2100) periods over most of Canada. The remarkably fine scale climate model outputs are essential data to characterize severe storms and droughts and to drive hydrological models with greater confidence than was possible with coarser scale regional climate models. From this data Climate Related Precipitation Extremes and Short Duration Extremes projects have been able to analyze specific scenarios to guide work with different industry sectors including agriculture, hydroelectric utilities and engineering design. For example, studying the regional and local atmospheric conditions affecting spatial distribution of extreme freezing rain accumulation causing significant storm damage to power infrastructure for New

Brunswick Power and Manitoba Hydro who have both experienced unprecedented damage and costs to wood poles, transmission towers and power lines in recent years. Work will now continue on understanding the likelihood of similar events in the future, a critical issue of public safety and infrastructure costs. Another example is the project's active involvement with the engineering community and the National Research Council (NRC), which is the federal government agency responsible for maintaining and regularly improving Canada's national building code and is a key source of input to the Canadian Highway Bridge Design Code that is the responsibility of the Canadian Standards Association. The NRC has been leading a large project that aims, ultimately, to develop guidance on impacts of climate change on infrastructure, including flood risk to buildings, changes in extreme rainfall, snow loads, and wind pressures during heavy rain that affect buildings, and changes in ice accretion that affect bridges and highways. The work that is being done on precipitation extremes and the mechanisms that produce those extremes in this project has informed presentations and reports to the NRC, and has helped to inform discussion of proposed changes to engineering design practices, which would create the need to focus on extreme return levels for much longer return periods than is currently required in Canada's building codes. This body of work has also informed an extensive ECCC-led assessment of projected changes in Canadian engineering design values.

- The Integrated Modelling Program for Canada project has used output from the fifth generation of the Coupled Model Intercomparison Project (CMIP5) available from the C3S Climate Data Store to drive future streamflow projections in the Nelson-Churchill basin. Results show scenarios of future runoff, snow water equivalent and evapotranspiration in upstream sub-basins that are critical information for understanding implications for hydroelectric facility operating ranges where small changes in water supply can cost millions of dollars in lost hydropower revenue and large infrastructure requires a 100 to 500 year time horizon for planning and licensing. Manitoba Hydro utilizes these models and simulations of future hydrologic scenarios as input into their long term hydroelectric generation planning and resource operations modelling. They need to know what to expect on long-term horizons because they are building generating stations today that will be in service for 100 years or more. Across the Canadian Prairies, climate change translates to more uncertainty in the water supply and without significant capacity to store water, Manitoba Hydro must ensure they can meet hydropower demand from the water that flows - even under drier conditions. This work and modelling results were featured on Copernicus, a central European data hub to support decision-making around the sustainable management of resources and provides information services focused on six themes of atmosphere, marine, land, security, emergency and climate change. Users can access the interactive story map and select between tabs to compare future climate trends.
- TTSW is working with industrial partner, Honeywell, to design the concept, mission potential and funding opportunities for a microsatellite mission that is currently being considered by the Canadian Space Agency (CSA). The project is developing and testing technologies planned for the mission concept as well as several possible funding opportunities are being considered (e.g. CFI with CSA and others as partners). To help make the case for this mission, TTSW and the GWF head office met with the Canadian

Space Agency and they have surveyed international water researchers to identify priority needs that could be achieved through a microsatellite mission.

- Results of NWF field research were presented to stakeholders at Husky Energy and members of the GNWT and the Environmental Science and Research Board of the NWT in Calgary. The information was explained from the point of view of how the data could be used to inform sustainable shale gas/oil development within the Central Mackenzie Valley and to quantify changes in landscape due to climate warming.

Non-Governmental Organizations

- Prairie Water is helping to inform the Redberry Lake monitoring program, an initiative led out of the Redberry Lake Biosphere Reserve. Project researchers are working with stakeholders in the watershed to conserve natural areas for species at risk and ecosystem services and they lend scientific expertise to help co-develop research with partners.
- Agriculture Water Futures, FORMBLOOM, Lake Futures, eDNA for Healthy Watersheds and Watershed Stressors projects all work closely with the Grand River Conservation Authority which manages water and other natural resources on behalf of 39 municipalities in Ontario and close to one million residents. GWF projects have actively collaborated with the GRCA to support the actions in their Watershed Management Plan to achieve its four goals to improve water quality; ensure water supplies; reduce flood damages; and build resilience to deal with climate change. For examples, FORMBLOOM has developed a clear and detailed understanding of the seasonal evolution of GCRA reservoirs that leads to cyanobacteria blooms including the role of extreme precipitation events, and provided the most detailed biological and chemical sampling of two of reservoirs including high resolution and high quality cyanobacteria toxin analyses. This work has contributed to a better understanding how climate, land use and various management practices affect water quality and algal blooms in streams and reservoirs in the Grand River. Lake Futures has detailed budgets of nitrogen and phosphorus legacies in the Grand River Watershed, and estimates of lag times between making changes in the landscapes and water quality improvement. This research has shown that some of the work being done on the Grand has indeed contributed to water quality improvement, albeit sometimes with decadal scale lag times. The Linking Multiple Stressors and eDNA projects make regular presentations to the GRCA on topics of interest to their manager, including fish responses to contaminants, models for studying multiple stressors in fish species, and fish responses to wastewater treatment upgrades.

5. Examples of applicable science innovations and commercializations

Modelling

- Through the Linking Multiple Stressors to Adverse Ecological Responses Across Watersheds project, the team developed a model to assess the value of major infrastructure investment in the Waterloo Region treatment plants and contribute the environmental data necessary for the treatment plant to develop, test and validate the environment fate and

effects components of the models. Of particular note is the decline in estrogenicity of final effluent after the implementation of nitrification at each plant. Estrogenicity declined from >20 ng/L to less than 1 ng/L in both effluents and our fate model was calibrated to the decline in fish intersex in the receiving environment. There was also a distinct decline in many pharmaceuticals such as ibuprofen and naproxen immediately after upgrades but several compounds, such as carbamazepine and venlafaxine (antidepressant) have remained elevated despite the upgrades. These compounds have the potential to alter metabolism and reproductive behavior of fish. In response to this concern our team has secured new funding through the National Contaminants Advisory Group, Fisheries and Ocean Canada, ($219,420 May 2020 – Mach 31, 2023) for "assessing the potential effects of representative chiral pharmaceuticals present in upgraded municipal wastewater effluents". This will be a legacy of the GWF as this new project will continue the model development initiated in the GWF program.

Sensors and other Monitoring Technologies

- MacVicar, B.J., C. Muirhead (patent pending) Self-Righting Radio Tracking Tags for Measuring Flows, United States Provisional Patent Application No. 62/801,277, filed Feb 5, 2019, MT Ref: 0232921.0002.
- Through the Transformative Sensor Technologies and Smart Watersheds (TTSW) project, researchers developed, deployed and commercialized the System for Acoustic Sounding of Snow 3 (SAS3 CHIONE). During recent field experiments, Chione was mounted to take acoustic measurements of a deep mountain snowpack at the Canadian Rockies Hydrological Observatory. Source signals were compared to determine which signals ensured the most accurate measurement of snow properties using an inverse model. A novel signal processing technique was implemented to determine the attenuation of sound waves in the snowpack to estimate snow depth for calculation of SWE and the maximum depth of propagation of the acoustic wave in snow. CHIONE has since been deployed to sites in the Prairies (Clavet, SK), Western Boreal Forest (BERMS, SK), Yukon shrub tundra (Wolf Creek, YT), Eastern Boreal Forest (NEIGE Site, PQ) and Spanish Pyrenees for extensive testing. The instrument has been presented at several scientific conferences including the International Union of Geodesy and Geophysics (IUGG) and the Canadian Geophysical Union (CGU), as well as to Minister of Science, Kirsty Duncan.
- Through the TTSW project, researchers developed and deployed an ultrasonic sensor for multiple environmental measurements. The sensor uses acoustic reflectance principles to infer water level and streamflow. This device is currently being tested in summer and winter conditions on the North Saskatchewan River (Borden Bridge) against the Water Survey of Canada (National Hydrological Service of ECCC) streamflow and depth sensors. The team continues to work with the Water Survey of Canada to implement the technology across their stream gauging network in the future. They have initiated discussions with Campbell Scientific about the possibility of commercializing the device in Phase 2 of TTSW. It has also been demonstrated to Kirsty Duncan, Minister of Science.
- The microfluidics lab led by Carolyn Ren has successfully established a cost-effective microwave system integrated with microfluidics for sensing (TTSW).

- The technical team of the Transformative Sensor Technologies and Smart Watersheds (TTSW) project, has been working to integrate a new hydrologically triggered data logging and collection platform in collaboration with industrial partners Solinst Canada, Honeywell and Myriota. This technology has been applied in the watershed monitoring networks within the Alder Creek observatory and the Norman Wells observatory. The new hardware being developed by each of the partners has been integrated to collect terrestrial data in response to temporal hydrologic conditions and transfer those data to low elevation satellites. Additionally, new applications of terrestrial EM-based geophysical mapping tools are being implemented at several of the GWF observatories with the direct application of mapping active zone thickness and soil frost dynamics.
- TTSW also mentions a number of other newly developed technologies:
    - Development and deployment of a Portable Waveguide Spectrometer (PWS) for the identification of water pollutants
    - Development of new groundwater monitoring techniques for the collection of samples within the active zone above permafrost
    - Implementation of geophysical techniques for application in remote terrain within the Central Mackenzie Valley, NWT
    - Field hydrologic tracer test - Within the Alder Creek and Washington Creek watersheds in southern Ontario, we have (in collaboration with the eDNA project - Servos) completed an initial proof of concept for a field hydrologic tracer test to collect integrated information on biologic and hydrologic processes within the watershed.
    - GNSS-Reflectometry has shown potential for estimating snow and ice thickness based on observations and data collected during a GNSS-R field campaign in March 2019.

Protocols and Methodologies

- Transformative eDNA and Omics approaches and protocols have been developed and are being refined to provide cost- and time-effective, targeted aquatic biomonitoring methodologies for governments, industries and community organizations. To date, 35 Standard Operating Procedures have been developed and are publicly available, including the detection of SARS-CoV-2 (the virus that causes COVID-19) in sewage water; protocols for water sampling and eDNA analyses have been transferred through training workshops with water management professionals, including the Saskatchewan Ministry of Environment (SME); and a pilot project with a mining company is helping to investigate the functionality of the methodology to meet requirements under the federal Environmental Impact Assessment program. The SME is now actively deploying the water sampling techniques in their annual lake monitoring program for the early detection of aquatic invasive species (Zebra Mussels), with analyses being performed in partnership with the University of Saskatchwan's Toxicology Centre. Project researchers are also actively expanding this work in a timely way to apply eDNA techniques and protocols to the identification and control of COVID-19 including through the Canadian Coalition on Wastewater-Related COVID-19 Research, a national collaboration of municipalities,

utilities, researchers, public health organizations and governments with the shared goal of advancing Canada's ability to support decision-making for public health protection and surveillance.

- Given the importance of understanding how much extreme precipitation will change in urban areas of the Saskatchewan River basin, where short duration high intensity events cause flash flooding, the GWF Core Modelling Team has carried out frequency analysis of these events for Calgary, Alberta, and Intensity Duration Frequency (IDF) curves were developed. In partnership with (and leveraged funding from) the City, ready-to-use empirical form of IDF curve has been proposed from this analysis for the City of Calgary. This provides a blueprint for other studies that aims in assessing the impact of future climate change on the streamflow and flood frequency analysis for major rivers that flow into urban areas and it can be taken as a pilot study for Canada. The flow duration curves developed from this study can be used to estimate flood frequency for floodplain mapping purposes if they are used as inputs to locally develop hydraulic models of the region of interest. This could be the basis for a coherent national approach to floodplain mapping that considers both non-stationarity due to climate change and uncertainty from climate models. Adopting this state-of-the-art approach would make Canada a global leader in assessing the risks of changing flooding due to climate change.
- The Prairie Water project has developed a novel, virtual watershed approach to predict water and watershed futures under changing climate and land-use scenarios. A virtual watershed is a tool through which the behaviour of typical or characteristic watersheds can be assessed instead of analyzing few watersheds using highly detailed and site-specific information (which is often lacking). Instead the approximate 'virtual' behaviour of thousands of watersheds in a way that makes it possible to represent the behaviour of the broader landscape. This framework has been informed by extensive stakeholder engagement, including experiential decision labs, and is being used to assess the response of water under different climates and real-world water management scenarios. The virtual watershed model outputs have now been linked to models of wetland water chemistry and biodiversity which required significant collaboration between co-investigators, HQP, and partners such as the Canadian Wildlife Services, Birds Canada, and Ducks Unlimited Canada, to decide on model spatial and temporal scale, output and input needs, and salient scenarios of land management. As a result, this framework integrates knowledge of regional hydrology and landscapes and permits first generation modelling of biochemical function, nutrient loads, and biodiversity outputs. The virtual modelling of the Prairie Pothole region is actively informing current policy programming including the Saskatchewan government's Agricultural Water Management Strategy and compliance programs and has contributed module content to an educational program for producers in Saskatchewan on natural resource management and resilience to climate change impacts led by the Saskatchewan Water Security Agency and Saskatchewan Association of Watersheds.
- Digital communication tools help researchers tell their stories in new ways that can be more effective methods of reaching a broader audience. Several GWF projects have focused on digital storytelling methods to create videos that not only highlight the research, but the

personal stories and connections involved. Northern Water Futures (NWF) has supported graduate student training to support the creation of short videos that are available on their YouTube Channel. These stories are linked to social media feeds (twitter and Facebook) to reach a wider audience. Longer videos have also been created showcasing research on water issues in the Prairies (Prairie Drainage Governance – link), and methodologies (Adaptation Governance and Policy in Relation to a Changing Moisture Regime - link) as well as highlights from across the network (GWF YouTube Channel). GWF researchers have also co-produced Podcasts with research partners to highlight ongoing initiatives.