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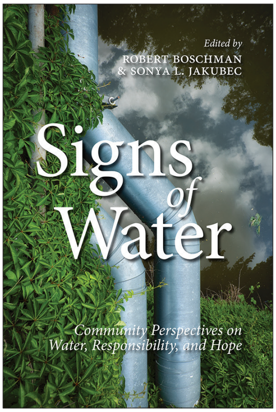

SIGNS OF WATER: COMMUNITY PERSPECTIVES ON WATER, RESPONSIBILITY, AND HOPE

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Large-Scale Water Harvesting: An Application Model in the Time of Accelerating Global Climate Change

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Water is vital to all living organisms, environments, and economies. Freshwater is a major strand of the Canadian national identity and a crucial resource for all other countries. Unfortunately, there is not enough systematic and joint talk about water issues from the federal and provincial perspectives, even though there has been a lot of environmental talk centered on global warming. The irony here is obvious because water and climate change are interconnected (Scarpaleggia, 2017). One of the major causes and drivers of climate change is water. Water state (solid, liquid, or gas), distribution through the spheres, usage, and quality highly influence the temperature regime of the atmosphere and surface. Similarly, water affects soil quality, erosion, wind patterns, the movement of weather systems, and the life cycle of everything on the planet. Climate change influences dry and wet spells with greater intensity creating extremes we have not seen before, while, at the same time, our coping capacity for either extreme is still low in many countries, including developed ones such as Canada.

Climate change also brings up some crucial questions:

1. How will the hydro-climatic conditions of watersheds react to global climatic and environmental changes, particularly to the aforementioned new extremes?
2. What will be the future of water quality in response to hydro-climatic changes, agricultural activities, industrial developments, land use change, and water management?
3. How can basin-wide water management and decision-making processes be improved under the new hydro-climatic and water quality conditions, where areas/regions/countries are impacted by vast social, economic, and environmental issues (Pomeroy, 2017)?

Adaptation to inevitable change and threat mitigation requires new science to understand the changing Earth system and new approaches (Wheater, 2017), a different rhetoric, and acceptance of new ideas and long-term projects that influence structural improvement in water resources and the water hydrological cycle. Humanity has already influenced all natural processes; it is now a question of whether we can remain in control and engineer a sustainable environment or not. In this chapter, I will address our ability to influence large-scale hydrological processes.

Hydrological Cycle

Human society depends on natural resources for every segment of our existence. Air, water, land, mineral resources, plants, and animals are crucial for our own survival. Unfortunately, even while as a civilization we do not possess complete knowledge of how everything in nature is connected, we destroy, shape, and forever change the environment that we are so dependent on. Above all, we still cannot foresee the whole spectrum of the influence of our actions and how the changes we initiate will evolve under future environmental conditions.

The hydrological cycle is the most fundamental principle of hydrology (Maidment, 1992). It influences climate and weather patterns, land characteristics, biosphere development, and human lifestyle. Practically, the Earth as we know it is shaped by water. Unfortunately, we still teach the classic model of the hydrological cycle, which does not exist anymore. The extensive influence of human factors on the hydrological cycle has been recorded for thousands of years. Every aspect of human living changes the water ways and shapes the hydrological cycle. In the vast majority of countries, ground waters are highly depleted, which of course influences the amount of water on the surface and in the atmosphere.

Structurally the "humanized" hydrological cycle influences the stability of all interrelated processes. The water cycle, today, is ruled by a domino effect that spreads through all spheres of existence. It is time to revisit the rhetoric about climate change and realize that humans have already reengineered the earth. With the transformation of the earth's surface and the hydrological cycle, we have forever altered weather patterns and the water regime.

Nevertheless, there is an opportunity to build a sustainable society, resistant to future alterations with a respectful approach to the environment. A "new" hydrological cycle can be reconstructed, and it could provide sustainability through rain and flood water harvesting. The water cycle is the key factor that we can influence to unlock the full potential of supervised geoengineering and make things, hopefully, better.

The hydrological cycle is the true connector of each segment of the earth system. Water is everywhere. The amount of water in each segment of the hydrological cycle influences the speed of change and the timeline of the processes. Tapping into the power of the hydrological cycle is crucial to stop, reverse, or redirect the climate (weather) pattern changes unfavorable to humans and the environment in general. Moreover, control of the hydrological cycle would provide a significant headstart in the second stage of geoengineering: reforestation, reshaping of desert into fertile land, enhancing sustainable urbanization, conservation of more natural spaces insisting on exclusion, and returning nature to true wild life away from human influence.

Even though this sounds like science fiction, water harvesting and redirection are already taking place in humanized zones and already changing environments. Planning for those actions on a large scale would increase our environmental capacities to cope with negative human impacts. Rain water harvesting and flood water harvesting are not new concepts; they have existed for thousands of years. Unfortunately, in our continuous growth, economically driven decision paradigm, economic and political interests see the uncertainty of weather-dependent sources as a liability. Thus, science and engineering have focused for centuries on slow-pass water resources, such as ground waters and big surface-water bodies.

Today, after thousands of years of exploiting "invisible," once-thought-to-be infinite ground water resources, we need to learn the role groundwater will play in defining water security. Groundwaters are worryingly depleted, while all the water ever released into the atmosphere influences the intensity and frequency of weather events. Higher concentrations of water in the atmosphere, combined with an elevated level of pollutants, indicate higher probabilities for weather extremes, such as torrential rain and extreme drought. In simple terms, the more water we place into the atmosphere, the more this changes the weather patterns that we notice. Moreover, in addition to the high rate of global groundwater exploitation, a high rate of evaporation and widespread Arctic and Antarctic ice melting adds to the seriousness of induced changes on the hydrological cycle.

To be able to focus on solutions, we have to stop separating groundwater and surface water in water management, and acknowledge that the air-soil-groundwater-surface water interface is the very essence of how the hydrological cycle works (Sandford, 2015). Only then can we notice a couple of spots within the hydrological cycle on which we can act to induce positive change and model climate back towards a life-supporting one. Considering water quality, quantity, and importance for life, water harvesting could be safely and sustainably conducted from the atmosphere, flood waters, and oceans. Each segment needs to be planned and interconnected with the other systems for water allocation and exploitation already in place. Harvesting deposition of rain and flood waters in underground systems of reservoirs would provide a significant enough delay in evaporation and mimic natural replenishment of ground waters and natural water flow.

In this chapter, large-scale water harvesting only considers organized and controlled rain water and flood water collection and the redistribution of rain and flood waters. Large-scale rain and flood water management is a radical change from the status quo, with long-term impacts and a long-term need for investments, but it is highly relevant and feasible in ameliorating our current environmental situation. It is worth consideration, discussion, improvement and, in the end, investment and realization.

Most importantly, it is possible and—if properly done—it would provide benefit to all life.

Non-Urban Large-scale Rain and Flood Water Harvesting Systems Implications and Use

To properly manage water, we have to understand its dual nature:

1. Water is a constituent, initiator, and catalyst of all natural processes crucial for the maintenance and creation of life on the planet.
2. It is an irrepressible resource and base for economic and social development.

As majestic as it is, still, water is vulnerable and dependent on the soil quality and chemistry of the atmosphere; and it is very susceptible to anthropogenic influence (pollution and overuse). Sustainable water management considers both roles and aspects of building resilience of water supply and the social resilience to water-related hazards. Environmental design is about working with water flow. At this moment, we already have many systems in place: urban elements (buildings, infrastructure, transit ways, parks, wastelands); rural communities, protected areas, designated areas for special purposes (mines, oil and gas, military); Indigenous lands; and border areas. It is impossible to ignore existing systems while designing an efficient and sustainable water redistribution and protection system. However, as water flow is all about energy, it is energy efficient to take into account the flow of water as the starting point of sustainable design. Blocking water flow causes stagnation, raises the risk of flooding and loss of biodiversity. Open water sources in stagnation are of lower quality than the ones with a steady and regular flow. Considering the appearance of water in nature, at first glance it is not most obvious that the best place to let water flow and redistribute is underground. More than 60% of fresh water lies in the ground, ice, and permafrost, while the other 40% is distributed within the atmosphere, rivers, swamps, and marshes, soil moisture, lakes, and living things. Accounting for two crucial things—water flow and underground (or in soil) storage—a sustainable water harvesting system can be designed.

An example of such a system is over 3,000 years old. Qanat is the generic term for an ancient environmentally sustainable water harvesting method and conveyance technique believed to have originated in Persia in the early millennium B.C. (Guliyev & Hasanov 2012; Middle East Institute, 2014). This amazing technology—known as *falaj* in Oman, *khettara* or *foggara* in North Africa, *karez* or *kanerjing* in the northwestern desert of China, and *karez* in Afghanistan, Pakistan, and Central Asia—continues to provide reliable supplies of water for human settlements and irrigation in hot, arid, and semi-arid climates. In fact, qanat technology exists in more than thirty-four countries. In Iran alone, there are an estimated 50,000 qanats, nearly three-quarters of which are still working. In Oman, there are more than 3,000 active qanats (aflaj). The qanat system (Wessels, 2014; Lightfoot, 1996) consists of a network of underground canals that transport water from aquifers in highlands to the surface at lower levels by gravity.

Qanats are classified according to the following criteria: length and depth of the qanat, topography, and geographical situation, type of aquifer, qanat discharge, and source of qanat flow. Classification according to the source of qanat flow is the most interesting one, as this indicates that the use of the qanat should be restricted to harvesting ground waters. However, the reality is that the water flow through the qanat may not be due to ground water seepage into the qanat's gallery, but to other sources such as a nearby spring or river, or could be fed by rainwater (Semsar Yazdi & Labbaf Khaneiki, 2010). By this criterion, we can classify qanats in four types:

A. Normal qanat: a normal or simple qanat drains groundwater, which directly enters the qanat production section.

B. Qanat-spring: when, in addition to ground water, spring water enters and feeds a qanat's water.

C. Qanat-river: this qanat resembles the spring type, except that it receives a surface stream (whether permanent or temporary created by storm water). In most cases, it is used in situations when it is impossible to transfer river water to the desired lands by gravity flow through open trenches, because the river bed is lower than the irrigated land on either side. Therefore, digging an underground conduit is helpful to sort out the topographical problem. The structure of this conduit resembles that of a typical qanat, but its water has nothing to do with harvesting an aquifer.

D. Qanat-well: is a hybrid combination of pumped well and qanat. In cases where the groundwater table drops down below and does not feed the mother well, the mother well in that case is deepened and equipped with a pump to deliver the water up to the gallery.

The rapid depletion of ground waters, as well as decline in their quality, is becoming a problem of great priority to be solved. In Canada, for example, the vast majority of rural areas are dependent on local wells and there is no continuous or appropriate monitoring of availability of ground water. Besides, the sheer size of Canada represents an obstacle to implement a continuous and centralized water supply to all inhabited areas. As many small communities are located between forests and green belts, traditional water supply systems would be costly and unsafe. But implementing traditional qanat knowledge in remote areas would ensure water supply in dry periods, in addition to drainage in periods of intense rainfall and flooding. Contemporary structures usually usurp the habitats of animals and affect biodiversity of local flora. Allowing water to flow underground while still being accessible for extraction would create a better and safer environment. Considering recent natural disasters in Canada, such as Alberta's fire in 2016, access to water on the spot would ensure timely reaction and the prevention of future disasters. As a qanat system could be adapted and supplemented with an underground reservoir, as well as open surface reservoirs, the system could provide a continuous flow of water through remote areas and re-direct water from one watershed to another without interrupting life on the surface.

Indigenous knowledge of water collection and living with the moody character of water should also be incorporated in sustainable water management and planning. Resilience is part of sustainability. Water is a major attribute of many disasters and should be considered more as a character than as a resource. It has its life, its ways, and its rhythm. Listening and following water ways would allow us to visualize the invisible network underground, which can be wisely modified into a system that we can actually see and use.

Humanity has already gone far along the path of engineering the Earth. We cannot just simply sit and say no more. Infrastructure that cuts through the veins of Earth leaves deep scars and changes all that ever was. Now it is time to humbly consider how we can work with water, ground, and sky with the aim of preserving life on the entire planet. And water is the best place to start.

Remote areas of the globe hide risks of great magnitude, as was learned from recent events in Alberta. Those risks will not be avoided in any other place on Earth. Disasters await the right circumstances. To anthropomorphize this thought, we could say they are patient and will uncover themselves when and as they see fit, if we do not bridge the gap between nature and people and start working with nature. Cities and all human infrastructure, along with the exploitation of natural resources, change environment with every second of the day and every breath we take. We at least should embrace the idea that by allowing water to flow and by reconnecting watersheds, we are ensuring that we will have water when there is no rain, and that by building protected underground reservoirs, we will at least raise our resilience to the inevitable change that is coming.

Underground Reservoirs and Dynamic Flow Re-Distribution Systems

Water has a high need to move in order to preserve its natural characteristics. Systems that provide water movement, but prevent excessive evaporation, are a crucial element for water conservation and protection. By protecting water, one protects society (Neill, 2016). By allowing water to be available in current zones of human occupation, one prevents migration and confrontation over the most important resource after clean air.

In 2008, the USA National Research Council gave a detailed overview of underground water systems that could resolve a future water crisis (Committee on Sustainable Underground Storage of Recoverable Water, National Research Council 2008). Even though concepts and practices of sending rain and surface water to underground systems have existed for thousands of years, the terms used to describe them vary widely and have changed over the years. As described by the Committee, Managed Underground Storage (MUS) refers to the deliberate placement of water into an underground location through a recharge method. With an intention for future reuse, this method could include surface infiltration and percolation through the vadose zone to a saturated aquifer or placement directly to an underground location.

Despite obvious benefits from MUS, there are also questions about consequences of the use of such systems at large scales. Since 2008, there have been no visible global commitments to research the implications and impact of interconnected managed underground water storages on a large scale. Questions of water quality, ground stability, implications of landslides and earthquakes due to change of ground saturation in percolation zones are just some of the technical issues to resolve. Other more human-induced issues include the price of such water in case of reuse, water rights, and water security including intentional threats to water quality. Understanding the effects of the underground aquifers can indicate whether the consequences of MUS, either beneficial or detrimental, will be long term, and whether it will have a significant environmental effect. Nevertheless, the need for managed underground "rivers" will only grow in time of great extremes such as more frequent floods and droughts. With plans for sustainable development and more coherent urban planning, urban zones will be even more dependent on proper, timely, developed, and efficient underground systems.

The aim of water harvesting is to collect urban runoff, surface runoff, and/or flood water surplus, and to store it and make it available when and where there is water shortage. This can be achieved by either

1. Impeding and trapping water in maximised individual storage units, or
2. Developing a water transit network among optimised individual reservoirs.

Harvested rain water and flood waters have a tremendous potential for meeting both indoor and outdoor water demands. With advanced landscaping that is both beautiful and functional, a significant amount of water can be collected, saved, and redistributed. We can capture rainfall when and where it lands. Currently, most of the harvested rain water is stored in sets of water tanks or rain barrels. Statistics Canada projects a 140 billion litres per year savings in the Great Lakes basin with introduction of water conservation strategies like rain water harvesting (RWH) (Adamaley, 2011; Statistics Canada, 2010). Unfortunately, RWH is still an untapped potential across the globe. The reason may be simple: those who have a significant amount of rain water to harvest have the least need.For that reason, a large-scale interconnected RWH system would ensure that water is diverted from areas where surplus is raising the risk of flooding to those areas in need of water.

Considering the need for urban space and the change of hydrology within urban zones, an underground network of water storage provides a solution for more than one issue. In crowded urban zones, the acquisition of the land for the purpose of flood or drought protection is quite problematic. In order to provide security and build resilience to natural hazards such as floods and droughts, an underground discharge system of channels and reservoirs is an adequate solution for the twenty-first century. Moreover, it is quite achievable as well.

An example from Japan shows that urban runoff can be successfully collected and relocated. A huge underground storm water drain system saves billions of dollars in flood-caused damages and prevents fatalities. Tokyo is shaped heavily by water. It is a densely populated area crisscrossed by rivers and channels that is geologically challenging; and it is situated on a flat floodplain of soft alluvial soil in a monsoon climate, with frequent typhoons on an active earthquake and volcanic belt. Not that long ago, in the mid-1900s, Tokyo's suburbs recorded a set of heavy typhoons and severe wet seasons followed by floods that destroyed large parts of the low-lying old downtown. Floods, back then, were a regular part of life. Over the last decades, Tokyo has built a new resilience against the forces of nature (Yu-Shou, 2016). A coordinated system of massive underground structures keeps the mega-city safe from the inevitable floods. There is high awareness that Tokyo has to be prepared and become resilient to the threats of global warming, floods, earthquakes, and a variety of other disasters. With an already very vulnerable geological position, more than a hundred square kilometres of the city basin is below sea level. Rapid industrialization made it even lower, and in the 1960s and 1970s the situation became more prone to disastrous floods.

Tokyo has an average annual rainfall of 1,530 mm, which is significantly more than most Canadian cities, with the exception of Vancouver (1,457mm), St. John's (1,534mm), and Halifax (1,468mm). But still none of these Canadian cities is experiencing pressure on its infrastructure as does Tokyo with 30 million people. In addition to the issues of dense population and vulnerable geographical predispositions, rising average temperatures and the additional heat island effect of the city are changing patterns of rainfall, adding to the complexity of the flood protection problem. Intense localized showers regularly deliver more than 100 mm of rain per hour. The occurrence of these heavy rainstorms has increased by around fifty percent over the last century. The traditional flood prediction approach, based on historical occurrence of floods, has been abandoned and due to the onset of sudden heavy rains, flooding is expected to occur at any time.

Tokyo's flood protection system originates from the early 1920s. An artificial waterway was constructed in 1924 in a junction with the Arakawa River. Its purpose was to divert flood waters away from eastern Tokyo which was a planned city growth area. Since the original design of the flood protection system, the flood discharge has doubled. Due to urbanization, the need for rapid drainage of storm water continues to grow with time. Lack of available land and repeated emergency situations led Tokyo to build an underground discharge channel. The surge tank is just the tail end of a flood control system that stretches another six kilometers underground, bypassing a low-lying basin. It collects water from five water courses, connecting all in one stream fifty meters under the surface of the city. Four modified aircraft turbines power the system, allowing two-hundred cubic meters per second discharge. The whole system is designed to withstand a once in two-hundred-year flood. The main objective of the facility is to reduce the damage caused by regular flooding. The sheer size of the structure is an engineering wonder. The cathedral-like chamber acts as a buffer in a flood emergency (see Figure 15.1)

Five stories deep, the surge tank is the length of two football fields. The purpose of the surge tank is to break the momentum of the water as it comes down from the tunnels. This giant system is designed so the

FIGURE 15.1. Water Chamber. Inside the 248,508 cubic feet water chamber, are five-dozen 60-foot high pillars, each reinforced by five hundred tons of concrete. Released under the GNU Free Documentation License.

tank never fills up and always discharges to the Eda River. On average, the facility experiences overflow to the chamber about seven times a year.

It took three billion dollars and thirteen years for Tokyo to build this system that saves astronomical amounts of money in damages. The Alberta floods alone will take over ten years of recovery with a projected cost of five billion dollars. There is a sound economic reason for implementing such a system in Canada. Due to its significant difference in geological as well as climatic characteristics, Canada has an advantage over Japan in availability of land, but on the other hand colder winters would require building the system below the frost line.

In as many cases as possible, a rain water harvesting system (RWH) should be combined with a flood water harvesting system (FWH). The early harvesting of water within a river bed results in lowering the risk of high peaks and overflow. It ensures an early stage of control of floods, with acting at the source of the problem and not just mitigating consequences. When the crown of the flood wave is reaching the peak, instead of allowing overflow and flooding, water could be collected in the river bed with systems based on sinkhole physics, bathtub overflow mechanism, and highway drainage systems. If we observe rivers as highways, we notice that accumulation is happening gradually but steadily like a traffic jam. Most of the solutions rely on releasing pressure through surface channels. But as land is as much a precious resource as water, there is not much space left to build more discharge channels. An underground system would allow the creation of many kilometers of pipes and tunnels in all directions without disturbing the surface. At the end of the system, there would be a reservoir to collect and store water for dry periods or discharge excess water to the most eligible river system or ocean.

As flood water is rising along the river bed, we can redirect that water to underground passage ways to avoid high water levels and overflows. The positioning of collectors at an optimal maximal water level would ensure enough water downstream for natural processes. Strategic positioning of these collectors at an adequate distance along the river would ensure steady drainage of flood waters as they accumulate into the river from rain, surface runoff, or tributaries. Collected water would not be wasted and instead be used for the regulation of water levels in river basins, drought preparedness, forest fire controls, or replenishment of ground waters.

Urban RWH is already implemented throughout Canada and the U.S. The City of Guelph, Mississauga, and McMaster University are some examples of good practice and long-term sustainable planning. Unfortunately, the approach to issues of rain water harvesting, flood water harvesting, water rights, and water redistribution is not coherent across Canada and the U.S. Opinions differ from province to province, as well as policies and rules.

Challenges of Implementation of Large-Scale Rain and Flood Water Harvesting Projects

The United Nations have already recognized the importance of rainwater harvesting as an environmentally sound approach for sustainable urban water management. Marginally larger rainwater harvesting and utilisation systems exist in the Changi Airport, Singapore, as well as Tokyo and Berlin. Storing rainwater from rooftop run-off in jars is an appropriate and inexpensive means of obtaining high quality drinking water in Thailand. Recognising the need to alter the drainage system, the Indonesian government introduced a regulation requiring that all buildings have an infiltration well. The regulation applies to two-thirds of the territory, including the Special Province of Yogyakarta, the Capital Special Province of Jakarta, West Java, and Central Java Province. In the Philippines, a rainwater harvesting programme was initiated in 1989 in Capiz Province with the assistance of the Canadian International Development Research Centre (IDRC) (United Nations Environmental Programme, 2017). Rainwater harvesting on a large scale is becoming increasingly important in the UK and the government has included legislation ensuring that new buildings now have to take into account how they deal with run-off water. The Code for Sustainable Homes, UK (Department for Communities and Local Government, 2014), also actively encourages the fitting of underground water tanks. The federal government in Canada, through the National Research Council and the Canadian Commission on Building and Fire Codes, produced the model National Building Code and the model National Plumbing Code. This document provides guidance for designing, constructing, and managing rainwater harvesting systems based on the minimum safety requirements established in these model national codes. It is important to note, however, that the provisions of the 2010 NPC have no force unless adopted by the applicable province or territory.

In Canada the applicable rainwater harvesting requirements are those set or referred to by the province or territory. This means the legality of rainwater harvesting differs from province to province. While in Ontario, as of the publication date of *Federal Guidelines* (Canada Mortgage and Housing Corporation, 2012), applicable provincial codes and regulations permit the use of rainwater for flushing toilets and urinals, as well as for sub-surface irrigation and below ground irrigation systems, in British Columbia the legality of rainwater collection is uncertain.

Kate Duke's (2014) inquiry into the right to capture rainwater is divided into four parts. Part one considers the nature of rainwater harvesting, its benefits, and its potential impacts. While rainwater harvesting has many benefits, it also has the potential to adversely affect instream flows and other water uses. Part two relates to the statutory framework of water allocation in the province and whether it affects the legality of rainwater harvesting. Although the legislation is not unambiguous, the right to collect rainwater does not appear to be affected by the Water Act or the Water Protection Act. Part three concerns the historical common law position on water-related rights. While there is some support for the proposition that a landowner has a proprietary interest in rainwater before it is captured, the most likely common law position is that rainwater is common property and subject to the old common law concept of the law of capture. Since this common law framework provides no redress to those who are adversely affected by rainwater harvesting, Duke's fourth point briefly addresses possible avenues for legal reform of the right to capture rainwater.

Water Balance Models

Besides the legal aspects of RWH and FWH systems, there is the issue of their impact on local wildlife, biodiversity, communities, economy, and climate change. To provide answers on these matters, water balance models (WBM) must be consulted in consideration of all possible scenarios. Good planning systems depend on continually updated WBM, great data mining, and assimilation of results generated from forecast models with on-site measurements and monitoring of the system in real time.

Water balance models have the aim of preserving an ecosystem's stability that redistribute excessive waters or give an alarm in case of water deficit for system. WBMs are a base for good dimensioning of water harvesting systems. WBMs are developed in order to understand the water cycle, protect and exploit water resources, and mitigate the negative impact of water resources on human infrastructures. WBMs have to consider in detail the water balance equation on five different levels (starting at Level 0 as shown in the formula to follow) and various time scales in order to create a full introspective in water "flow" through the hydrological cycle:

$$Level\ 0\text{:}\ \mathrm{AV_0(t+\ \Delta t) = AV_0(t) + S \cdot \int_t^{t+\Delta t} (P(t) - ET(t))dt} \quad (1)$$

$$Level\ 1\text{:}\ AV_1(t+\ \Delta t) = AV_1(t) + \int_t^{t+\Delta t} (Q(t) - N_q)dt \quad (2)$$

$$Level\ 2\text{:}\ AV_2(t+\ \Delta t) = AV_2(t) + S \cdot \int_t^{t+\Delta t} (H(t) - N_H)dt \quad (3)$$

$$Level\ 3\text{:}\ (-) Biological\ processes\ BM(t+\ \Delta t) = BM(t) + S \cdot \int_t^{t+\Delta t} Growth(t)dt \quad (4)$$

$$Level\ 4\text{:} (-)\ Anthropogenic\ influence\ - water\ consumption. \quad (5)$$

Components of the water balance are (1) atmospheric, (2) surface waters—visible water, (3) underground water—hidden waters, (4) biosphere, and (5) anthropogenic activities not reflected in either of the other four levels of equation. Each level 0-4 has a different spatial and temporal scale. Hydrological processes can take anywhere from seconds to hundreds of years. For example, on a null level happen instant processes such as evaporation on a hot summer day when one can see the shimmer in the air from water being pulled out from the surface by hot air. These processes feed the next level and are the leading water routes between spheres (bio-lito-hydro-atmo). The scale on which one observes the process changes the details that are accounted. On a grand scale, the hydrological cycle consists of a multiverse of small-scale systems contributing to global patterns. Changes on these levels contribute to weather pattern change, formation of drought, or torrential rains. Ultimately cumulative changes on a micro scale lead to climate change. Each equation's level consists of billions of participants—plants, soil types and ground structures, rivers, animals, and humans. Different plant types have different growth dynamics and need for water, various soils transport water differently, and people across the globe use water in numerous ways, often unmonitored. Each level is characterized by a different dynamic of internal change, mature plants vs. young plants, population migrations and growth—humans and animals, industrial processes, river meanders, ice cap melting or growth, tectonic movements and change in underground storage. The multilevel equation becomes even more complex when considering the time scales of multiple hydrological processes.

Each WBM has to:

1. provide information regarding how systems will change under specific influences and be a reliable tool in planning and infrastructural development;
2. predict and forecast at various times and spatial scales movement and distribution of water within the system;
3. reproduce the variability of hydrological processes;
4. have the ability to close water balance considering a full water balance equation.

Water balance models rely on many assumptions and categorically and intentionally neglect processes on lower time scales. Considering the time scale of different water hazards and processes, there is no unique model that we can use. We require a composite of different scale modelling to see the big picture. Uncertainties related to algorithms, approximations, and representativeness of observations exist in each model. Modelling purposes, target area, calculation method, temporal and spatial boundaries, available data and facilities, all these drive the accuracy of water balance results. Generally, the degree of accuracy of WBMs is determined before any computations (Ghandhari & Alavi Moghaddam, 2011). To achieve better results, the following four considerations in the modelling or in selection of the WBM should be included:

1. appropriate parent model;
2. avoidance of any unnecessary details in calculations;
3. using all available data and facilities; and
4. allowing for new scientific findings.

Prior to the design of any water harvest system, a reliable WBM should be applied for long-term planning. The aim of using WBMs is to provide adequate advice for infrastructural planning on a large scale that will ensure that built flood and rain water harvest systems will last at least 100 years and more.

We have to be aware that for all of these considerations we need time, with the realization that nature does not take a break. Each segment of the large-scale projects depends on

1. proper preparation and research of resources under impact of climate change;
2. environmental impact assessment of designed structures;
3. communication between communities, decision makers, academia, and all other stakeholders;
4. the existence of adequate policies and timely, proper implementation of these;
5. the willingness and readiness to take long-term risks and invest in the projects;
6. maintenance of long-term investments;
7. control of economic, social, health, and environmental risks;
8. investment in continuous education of future users and managers of the system, once built.

All of this and much more depends on the projections and advice based on WBMs. Furthermore, various software tools exist to provide water balance or hydrological modeling (SANTINEL-3, MODIS, TRMM, GPM, GRACE, SMOS, SWAT, HEC-HMS, DELFT-3D, MIKE, and others). Realizing that each and every WBM has its own uncertainties, we have to acknowledge that WBMS alone are not enough. Context is needed. Good WBMs are only the beginning. An example of good practice is the Global Water Future program, which focuses its scientific pillars beyond plain hydrological modelling and includes layers upon layers of crucial elements that run the Earth system and, within it, the hydrological cycle.

We are on the brink of endless opportunities to learn more by consolidating science instead of breaking it apart into traditional silos. Once WBMs have proper and detailed input data on a variety of scales, then we will have a reliable support system for long-term decision making and infrastructural planning. There is a great awareness that models depend on our overall knowledge of the system. By acknowledging the complexities of Earth's processes, and by including traditional knowledge and experience as well as incorporating system vulnerabilities, models will be better able to follow water through the hydrological cycle.

Conclusion

"Water in the end is the universal healer. Having it in any inadequate supply, either too much or too little, we expire at every level of our being" (Neill, 2016, 357). Redistribution of harvested water leads to change in all sectors of human society: health, education, and economy, as well influencing environmental change. The legality of the reuse of rain and flood water should be targeted on the community level, where the joint benefit of the community and environment would be the priority. Large-scale systems could provide enough technical space to locally generate energy applying small turbines on sections where water flow changes elevation. The standard method of operation is that a large reservoir of water is created by damming a river and then allowing a tunnel or pipeline of water, at the bottom of the dam, to flow past turbines on generators to turn those turbines and create electricity. Stauffer has invented an alternative method to create a pipeline of water that turns the turbines of the hydroelectric power generator and does not require a dam or a reservoir of water behind a dam. Instead, the powerful flow of water can be created by gravity in a submerged pipeline that flows from a higher elevation to a lower elevation (Stauffer, 2014).

Rain water management consists of three interconnected activities: harvest, recycle, and reuse. Benefits would outweigh any investment needed. The environmental price, if we do not invest in large-scale application of RWH and FWH, is the continuous and cumulative effects of floods and droughts, with impacts to environment, health, economy, development, and security. Financial losses caused by floods and droughts are counted in billions of dollars. The insurance industry will have a hard time covering all the damage to come, which will necessarily create greater policy costs. Arguably, the insurance industry may take first place in a long list of stakeholders who would benefit from large scale RWH and FWH systems, but many others would of course also benefit.

By intervening with water levels, we are influencing climate, land, and ecosystems. Canada, for instance, has a great opportunity to become a leader in this crucial sector for human survival. Having rich water resources constitutes a robust opportunity in research and development. Hydrologists and atmospheric scientists from across the country have clear evidence that Canada's climate is changing, and that these changes are being reflected in the timing and type of precipitation and in other factors that could affect water security (Sandford, 2015). Saving should start now.

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