Community-based Stormwater Smartgrids: Distributed AI/IoT Rain Harvesting Networks for Flood and Drought Resilience

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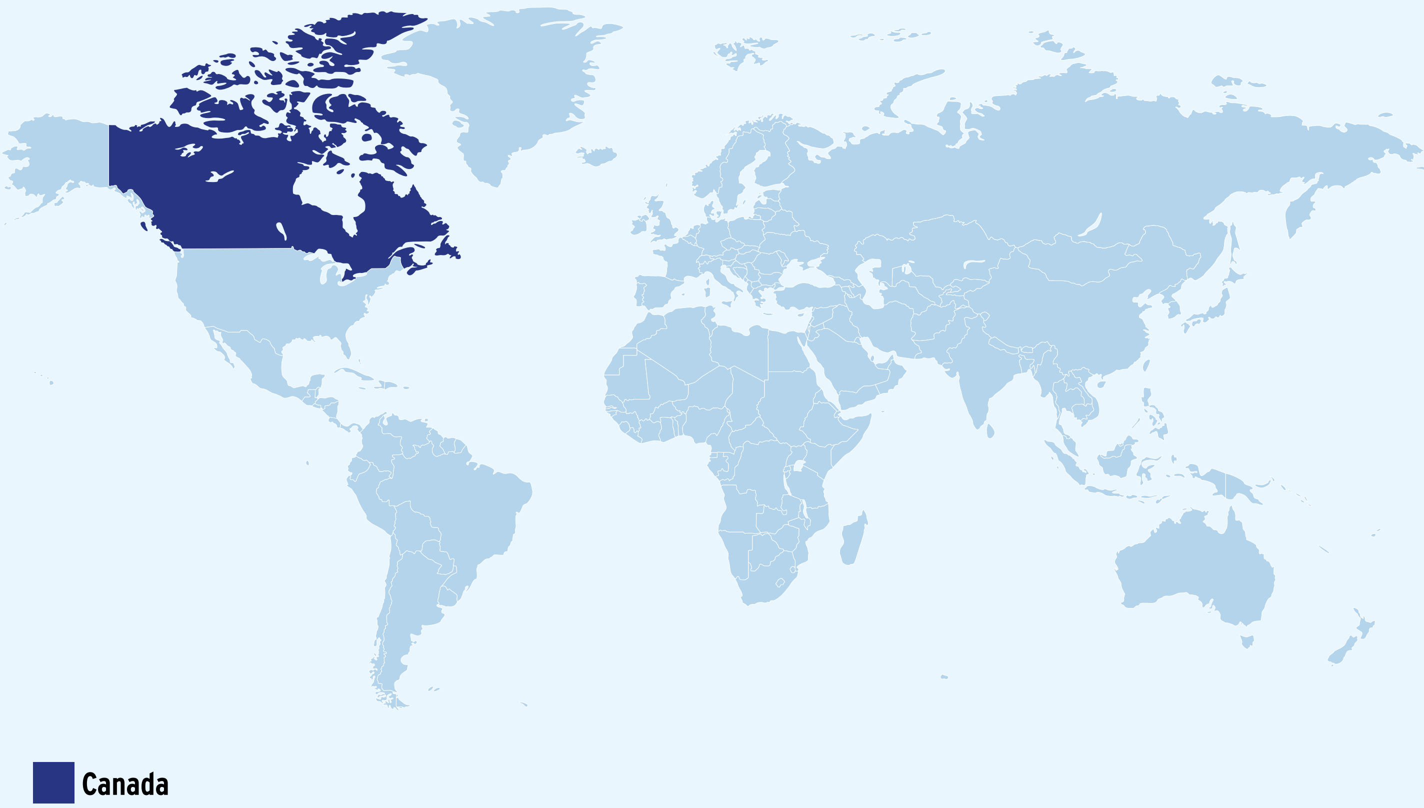

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Summary

Cities around the world, including in Canada, are committing to sustainable stormwater management, by increasing permeable surfaces through water sensitive urban design (such as bioswales, raingardens and permeable paving) or investing in stormwater harvesting to collect and retain large volumes of stormwater. These approaches help to reduce pollutants entering sewers and subsequently urban waterways. At the individual property or residential household level, rain tanks have similarly been promoted to collect rainwater runoff. However, property based rain harvesting faces the same problem as land based infiltration systems – how to ensure there is sufficient reserve capacity to reduce stormwater overflow, when the system is already storing a previous rain event. Households do not typically install sufficient capacity to undertake the sophisticated storage and release operations of commercial facilities' automation systems. As residential rain harvesting has relied on operation and maintenance by the property owner, municipal water utilities have been reluctant to incorporate it into urban water design.

To address this issue the RainGrid Stormwater Smartgrid was developed to apply real-time weather artificial intelligence (AI) management and internet of things (IoT) automation to passive residential-scale stormwater cisterns. The purpose of the AI is to determine how much rainfall will runoff from household roofs given the predicted rainfall and rooftop area, while the IoT automated cistern captures, filters and stores it in a suitably sized cistern. Thereafter the water is available for use in the household and garden as 1) recycled water, 2) groundwater recharge or 3) timed discharge into the sewerage system, by means of electrically actuated valves controlled by the IoT, until the next predicted rainfall.

A Stormwater Smartgrid operational data dashboard, specific to each property, visualizes the AI micro-climate rainfall data while on-board sensors calculate temperature, barometric pressure and rooftop runoff retained in the cistern. Extrapolating from these data sets we are also able to determine consumer behaviour regarding potable water demand offset, and potential flood and drought conditions in real-time, providing an exciting big data insight into community based rainfall patterns and property owner behaviours for utility operators. As the average household (or 'lot level') rooftop in Canada represents 40-60% of gross impermeable surfaces of the property, and residential rooftops represent an average of 47-56% of gross urban impermeable area, households offer an important but unmet opportunity for intelligent, climate resilience stormwater management. An average yearly rainfall of approximately 780mm in Canada over a typical roof size of 250m^2 yields 195,000 litres of water that can be captured and either reused or returned to the groundwater or sewerage system. Therefore by automating the operation of household rainwater cisterns, we can both achieve reliable, measurable and effective stormwater management as close to where the rain falls as possible (truly local source control), and increase access to carbon neutral water for environmental and domestic uses.

Beyond addressing stormwater challenges, the Stormwater Smartgrid also opens up the opportunity to generate highly granular (lot-level), optimally effective real-time microclimate data visualization and analytics. AI capacity to determine on a property by property basis when the next rainfall is likely to come, and to consequently empty cisterns to provide appropriate storage to ensure practically zero stormwater runoff from the rooftops that constitute the majority of urban impermeable area. This local climate data and distributed infrastructure should be extremely valuable for water utilities and municipalities.

This case study demonstrates the potential for the adoption of Stormwater Smartgrid technology to empower individual property owners to engage in and act on a shared community basis to ultimately make a significant difference to stormwater management in urban areas. It also shows the barriers that have been faced to date to implement this type of technology on a large scale. Among those barriers is the need to reach a 40% voluntary participation threshold to attain measurable volume reduction on the municipal system, the absence thus far of a business case utilities are comfortable with adopting, and the technical issues such as perfecting a cost-effective internet communications and power platform and effectively designed cisterns for year round operational reliability under various climate scenarios. It is hoped that by sharing this case study, others interested in smart technology for urban stormwater/water management capture and use will gain an understanding of the challenges faced, and the potential for moving forward.

1. Background

Traditional urban centres evolved their drainage practices to emphasize the rapid and efficient drainage of rainfall. As cities evolved, sanitary piped systems were typically used for street drainage and/or to convey rooftop runoff using the same pipes, a practice known as combined or semi-combined sewers. The outcome of which is that during wet weather events, in-pipe volumes exceeded the capacity of the piped conveyance, and by-passed contaminated flows to waterways.

To address this low impact development (LID) or green infrastructure (GI) has evolved over the past twenty-five years into a source control basic of urban stormwater management. As stated by the Ontario Ministry of Environment and Climate Change '*LID is an innovative state of the art approach to managing stormwater by first and foremost treating runoff (precipitation) at its source, as a resource to be managed and protected rather than a waste. In this regard, the emphasis is to maintain the existing pre-development water balance through the use of source (lot level) and conveyance measures in combination with end-of-pipe controls using what is referred to as a 'treatment train' approach to stormwater management.*' (Ontario Ministry of Environment and Climate Change, 2017)

That evolution itself reflects a recognition that the design and operation of conventional end-of-pipe civic infrastructure did not meet the need for an ecosystem, fiscally and operationally efficient urban water management approach. LID was designed to detain, retain and infiltrate stormwater in the highly impermeable urban landscape to re-establishing permeability or mimicking the timing of the natural hydrological cycle with appropriate scale engineered solutions. Stormwater LID was city building for water, and it evolved over twenty years after much debate and push-back from the highly entrenched engineering profession into standardized applications of bio-infiltration trenches, green roofs, street tree infiltration boxes, conveyance and property based rain gardens, and property based rain harvesting.

In the United States, Canada, the United Kingdom and other jurisdictions, utility owned and asset managed green infrastructure is generally only implemented on public property. Distributed residential and commercial property-based green infrastructure is not typically integrated into the asset management planning or costing of water utilities.

Water utilities and municipal stormwater programs illustrate this lack of property-based engagement most ably by the continued practice of distributing inadequately sized, passive and under-utilized rain barrels as public education and outreach engagement tools. Almost universally these programs do not achieve the water conservation or stormwater attenuation goals they espouse, but cities are wedded to them because they fulfil a low-cost, high profile community engagement role.

Within that context the age-old practice of rain harvesting re-appeared as an early staple of residential LID. It was determined that distributing large volumes of small rain barrels, citizens would be enhanced in their appreciation of stormwater runoff retention and potable water conservation. Unfortunately, most rain barrel programs achieved nothing of the sort. They exist as education and outreach trinkets, whose validity as LID has been unreliable, minimal to non-existent, and for the most part unmeasurable.

We say for the most part because in the U.S. there are a few MS4 (Municipal Separate Storm Sewer System) mandated utility LID programs delivering effective residential rain harvesting infrastructure – Washington, D.C.; San Francisco, CA; Seattle, WA. However, even these are universally passive in their technology. The promise of real-time IoT to enhance their reliability, measurability and effectiveness is dependent upon resolving the administrative barrier represented by the delineation of public versus private property. Until such time as that changes, most water utilities programmers will not undertake installing utility-scale, property-based intelligent rain harvesting infrastructure.

This condition exists notwithstanding The Nine Mile Run RainBarrel Initiative a definitive research study undertaken in 2003-05 in Pittsburgh, PA, to determine the positive impact residential LID methods, and rain harvesting in particular, could bring to reducing stormwater flows, combined sewer overflows and instream flows during wet weather events. The NMRRI analysis report shows that as little as 1m3 of residential rain harvesting retention significantly reduced stormwater infiltration of combined sewers, reduced surface runoff, in stream flows and overall pollutant loadings. (Three Rivers Wet Weather Inc., Nine Mile Run Watershed Association, RiverSides Stewardship Alliance, The Student Conservation Association, CDM Inc., 2005)

This was the definitive proof that residential harvesting of rooftop downspouts diverted significant enough volumes of rooftop runoff that it was possible to measure the subsequent reductions of thermal loadings, suspended solids and non-organic pollutants that make up stormwater as it transits from rooftop, across yards, sidewalks and roads into storm sewers (York 2017).

City and regional economies, whether in developed or developing nations, grow and prosper on their ability to provide safe and reliable water infrastructure, services and prices that advance the health, economic and ecosystem objectives, supportive of the sustainable development goals (SDGs). While the conventional centralized water and wastewater infrastructure business model is often seen as the best approach to manage water supplies sustainable, it is also partially responsible for the infrastructure deficits threatening their ability to maintain secure water services. The vast capital required for engineering design and construction is dwarfed by the operations and maintenance costs, including the extensive energy demand of pumping and treating water; one of the largest energy expenditures and GhG contributors of global cities.

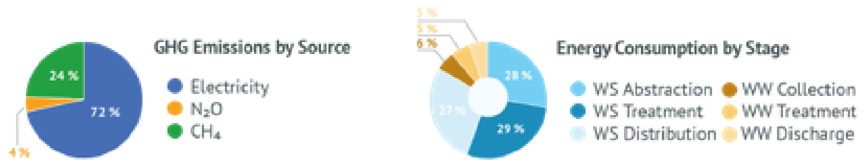

Figure 1. Energy Water Nexus Data International Climate Initiative – Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB)

Cities face an unsustainable fiscal burden associated with maintaining and expanding the highly-engineered, capital intensive conventional water systems developed over the past century. This accumulates as an infrastructure debt burden that reflects an unwillingness or inability to upgrade drinking water and sanitation infrastructure largely due to a lack of real-cost accounting. In the worst instance this results in societal disinvestment and decay of the infrastructure assets with a middle-ground occupied by privatization and the conversion of social good into profit (only leavened by good political governance), and in the best instances represents an opportunity for wholesale organizational, technological and fiscal restructuring of publically-owned utilities, including the adoption of intelligent, distributed water and wastewater infrastructure innovation.

Furthermore, cities' struggling to maintain their capital intensive, highly engineered, centralized water, wastewater and stormwater infrastructure are complicated further by climate change impacts, population shifts, and competition for limited fiscal and natural resources.
One of the major areas of concern for cities is stormwater and the impact it has on both water management and water quality. Non-point surface-runoff from urban and rural landscapes constitutes one of the largest pollutant sources for many cities, with a combination of pollutants including oils, grease, heavy metals, organic and inorganic waste. This is then coupled with the thermal loadings and sheer volume of stormwater, which after heavy rainfall is all magnified and accelerated by sewers designed to drain as rapidly as possible.

With regard to wet weather or stormwater runoff, and seasonal flooding, echoes the same 'infrastructure, fiscal, social and ecosystem deficit' language. Stormwater or 'drainage' infrastructure is the baseline upon which most societies have built their cities. The pipes and pumps that drained 'swamps', controlled flooding rivers, held back the tides, and most often corralled and drained away the rains as soon as they fell made habitation, farming, industry and other pursuits viable.

Builders for instance, perceive rain as the ultimate enemy, to be shielded from and protected against rather than taken into the building envelope. Buildings, landscapes, and even watersheds are hardened, even armoured against runoff through the introduction of impermeable surfaces (e.g. concrete, roads and footpaths). From where the rain falls to where it discharges into receiving water bodies, the traditional infrastructure of drainage is at odds with 'ecosystem' or 'watershed' based planning. The effect of this piped drainage and centralized stormwater management has been a magnification of impacts as increasing urbanization reduces permeability and natural hydrological flows, while variable climate change weather patterns challenge the ability of existing infrastructure design and sizing to cope with highly variable rainfall intensities, frequencies or temperature.

To simplify these myriad challenges, it is best to characterize the challenge cities face as determined by variability in the presence or absence of rainfall, and how much it will cost to operate and maintain water security, piped sewer systems and treatment facilities in cities coping with that variability of climate manifested stormwater or drought.

1.1 The Lot Level Approach to Stormwater Management and the Founding of RainGrid

Within the context of modern urban stormwater management, two trends have evolved that recognize and magnify the value proposition of distributed water infrastructure: 1) Low Impact or Sustainable Urban Design methods, and 2) intelligent technologies. Each of these interfaces with the existing conventional centralized infrastructure dynamic in a unique manner.

Traditional, centralised infrastructure is separated into three silos (drinking, waste and stormwater) all publically run. In modern urban stormwater management the thinking has shifted, and there is no such thing as 'wastewater'. The traditional three silos are now becoming a closed loop, or 'one water'. Rainwater harvesting takes rain where it falls reuses it on-site, usually at a small, lot level scale. The importance of small-scale and localised water is not often recognised, despite it being sensible water management to manage the water where it falls, as the lot level is where floods begin and where water demand originates. Despite the benefits and technological capacity to shift to a localized, decentralized approach to stormwater management, such a transformation poses concerns for public utilities. They cast this transformation as one of increasing the uncertainly around the safety and health of the community. Therefore, decentralisation of water management will need to have strong cooperation between utilities and the property owner for it to be successful.

IoT-enabled networks of utility-scale distributed rain harvesting infrastructure on private property have already evolved into a dynamic and promising future for city water security, and they encompass the complexities, barriers and opportunities of what would be a groundbreaking shift in water management in cities around the globe. Just as with distributed PV electrical production, the individual residential lot level is seen as ground zero in the debate over distributed water technology, and just as PV focused on rooftops, so does intelligent rain harvesting. The unrealised value proposition of utilizing individual rooftops derives from the fact they represent both the primary source for rain harvesting and the primary cost source for stormwater.

1.2 Public vs. private property for water management

What delineates whether as a public utility manager one sees the lot level as a value or cost location is determined by how one views the relationship between public and private property. The key to the rise of intelligent rain harvesting is found in the long standing debate between whether utility owned stormwater infrastructure can be constructed on private property. The typical municipal utility operates on an extremely unusual dichotomy of public and private. The whole notion of public services to individual properties – whether residential, commercial or institutional – is premised on maintaining a delineation between where the public (or private) utility places its infrastructure, and who pays for what. Water service utilities are responsible for centralized collection and treatment of wastewaters, and the provision and distribution of potable water – up to the property line. The piping of either service is the responsibility of the property owner, although it is typically regulated by strictly enforced building codes.

Municipal infrastructure has rapidly implemented distributed 'smart' systems utilizing AI (Artificial Intelligence), IoT (Internet of Things) automation, and software as a service (SaaS) data visualization and analytics for a wide variety of applications. When installed on a city-wide network or utility-scale, smart (real-time) distributed systems (i.e. decentralised infrastructure with central software analytics) have a transformative effect on the reliability, effectiveness, and monitoring of urban infrastructure and services.

For water utilities and users nowhere else does smart AI/IoT better illustrate its market disruptive transformative power than in the pivotal change brought to the previously passive, low-tech water conservation practice of property-based rain harvesting for conservation and stormwater management. AI/IoT has the potential to transform analogue rain harvesting (RwH) into a powerful, digital, distributed asset-managed infrastructure providing reliable, measureable, and effective operational capacity for flood and drought resilience, drinking water security of supply, groundwater recharge and climate adaptation/resilience, and highly value-added operational data visualization and analytics, and micro-climate data maps of rainfall and runoff on an individual property and city-wide utility basis providing a real-time analysis of how rainfall affects sewers, properties, neighbourhoods, and whole cities, and how harvested rainfall is used as security of supply for property-based potable water offsets of irrigation or toilet flushing, a stable source of groundwater recharge or environmental flows, or simply a low impact development detention for subsequent discharge to either surface or sewer systems following the storm event.

1.3 RainGrid

RainGrid is a climate adaptation and resilience company dedicated to technology and business model transformation of distributed residential rain harvesting by configuring it as smart city, utility-scale stormwater (flood and drought adaptation/resilience) distributed infrastructure. RainGrid evolved from the community based NGO RiverSides which delivered residential stormwater social marketing programs until morphing into the design and supply of rain barrel programs for cities.

In the process of discussions with a Washington, D.C. client about future-proofing the RiverSides' rain cistern, it became clear that analogue rain harvesting faced a market limiting future unless it resolved two challenges associated with the operation and maintenance of its products. Residential rain barrels needed a thorough redesign to reduce rising product and transportation costs, to increase operational efficiencies and to accommodate scalability. In designing a scalable, nestable cistern it was revealed that the original research challenge was really one that distilled into one challenge – owner operation and maintenance. One user issue, an ability to know the volume of the cistern and one programmer issue, ensuring that cisterns were emptied prior to subsequent rainfalls lead to discussions about automation, and from that an exploration of how the internet of things could be applied to residential rain harvesting. We believed that what the market needed was a smart cistern that would solve the social challenge of property owner management and maintenance of cisterns, and the administrative challenge of knowing that residential rain harvesting cisterns were emptied and available to serve as stormwater storage when needed as opposed to remaining full to serve their user's determined desires for water offsets. In short, these are two diametrically opposite goals for rain harvesting complicated by the passive, analogue cisterns. Solving for that challenge by designing a smart rain barrel that would resolved these two challenges for residential private property stormwater infrastructure is what engendered the founding of RainGrid in 2012.

At the beginning of the project our goal was to design an 'out-of-the-box' cistern retrofit, using an 'Internet of Things' (IoT) controller, and managed by weather artificial intelligence (AI).

As we developed several prototypes iterations of the technology, we also embarked upon solving the challenges related to the operational ownership of the technology, implementation, and business model.

RainGrid's 'lot level utility approach' facilitates the evolution of a community private public partnership (P3) business model, whereby residential property owners trade their property access for utility-owned and third party maintained intelligent infrastructure.

As RainGrid's Ai/IoT rain harvesting systems are capable of taking 90+% of rainfall runoff from residential rooftops, reducing the pressure on stormwater management for utilities, and providing data visualization and analytics of the captured rainfall, the Smart Cistern seemed to meet the consumer demand to know what was in their cisterns, and the utility's needs to control the water.

While utility-scale residential lot-level stormwater best management practice implementation is not yet readily adopted in municipal stormwater programs, the opportunity for tangible returns could convince municipal programs to convert their analogue residential rain barrel programs to digital read-time assets instead of passive education and out-reach tools.

CASE STUDIES
COMMUNITY-BASED STORMWATER SMARTGRIDS: DISTRIBUTED AI/IOT RAIN HARVESTING NETWORKS FOR FLOOD AND DROUGHT RESILIENCE

2. Water Challenge

2.1 Stormwater management

Stormwater management is an area of increasing concern as urban areas increase impermeable surfaces by introducing more concrete, roads and buildings. With reduced permeability in the soil surface, rainfall is unable to follow the natural water cycle by recharging the groundwater, and is instead forced to flow across impermeable surfaces, collecting pollutants along the way to drainage points.

The residential lot level typically constitutes 45% of gross impermeable area (largely rooftops) and encompasses a majority of the landscape of the typical urban residential development footprint. The reason why this is an issue is that impermeable surfaces stop the water naturally being able to reach the groundwater, therefore requiring more infrastructure to manage.

This has been addressed in the past by installing piped drainage systems, either through combined or separate stormwater sewers. Combined sewers are usually found in older parts of cities and carry both sewage and stormwater to wastewater treatment plants in one pipe (City of Toronto, 2017). Conversely, storm sewers contain only rainwater or snowmelt, which travel from roadside catch basins to receiving water bodies. Combined sewers can work effectively, but have negative environmental consequences during heavy precipitation events. When the volume of water exceeds the pipes' capacity, combined sewer overflows (CSOs) allow for the contents of the pipes to bypass treatment and go into the receiving body of water in order to prevent flooding of private property (City of Toronto, 2017). In order to prevent the negative environmental impacts associated with discharging untreated water during storm events, storage tanks and/or tunnels have been built in North America and Europe (City of Toronto, 2017). Examples of such are Toronto's Western Beaches Storage Tunnel and Eastern Beaches Detention Tanks, both of which intercept water from combined sewer overflows and stormwater. The storage time allows for settling before the water is subsequently pumped to the nearby wastewater treatment plant before being discharged back into receiving water bodies. While this solution addresses the issue of water quality associated with stormwater runoff and combined sewer overflows, the projects are largely capital intensive. For instance, the Western Beaches Tunnel cost $52 million in 2002 and required an additional pumping station (C &M McNally Tunnel Constructors, 2017). Similar projects are built around the globe and can be on a much larger scale. The Thames Tideway tunnel in London, England is currently under construction to address the problem of sewer overflows during heavy rainfall. The tunnel is to be 15 miles long and is expected to prevent 18 million tonnes of sewage from entering the Thames river (Gayle & Taylor, 2016). This project is estimated to cost £4.2 billion (Tideway, 2017), demonstrating the capital-intensive nature of such centralized solutions. These projects also take many years to complete, as the Thames Tideway is estimated to take 9 years from planning to completion; the Coxwell Sanitary Trunk Sewer in Toronto is planned to be constructed in phases over a 25-year span; and construction for the Anacostia River Tunnel Project in D.C is expected to take 5 years. As many cities experience the acute effects of climate change, the speed at which large centralized projects are completed may not be sufficient for adaptation and flood mitigation. In addition, whilst water is retained in storage tanks, it is alienated from the surrounding ecosystem.

Another common method of stormwater detention is the use of stormwater management ponds, which are prevalent in relatively newer suburban developments throughout North America. Within Ontario, they have become increasingly popular in the past 25 years (Drake & Guo, 2008). Upon the MOE recognition of stormwater management ponds as 'effective and efficient' stormwater management facilities, developers have been required to include them in subdivision designs (Drake & Guo, 2008). While these facilities mimic the natural environment in performing passive water quantity and quality control, they require regular monitoring and sediment removal to maintain performance. However, lack of budget and/or planning has resulted in the majority of stormwater management ponds being underserviced, and therefore underperforming, in Ontario (Drake and Guo, 2008).

Furthermore, the USEPA has expressed the shortcomings in focusing primarily on large infrastructure in stating that stormwater management 'needs to be designed as a system [that integrates] structural and non-structural [elements] and incorporate[s] watershed goals, site characteristics, development land use…monitoring and maintenance' (USEPA, 2008). These historically dominant practices of detaining stormwater on a centralized or regional basis have not been fully effective at protecting water quality in receiving water bodies or meeting flood control requirements (USEPA, 2008). Another increasingly common stormwater management method being implemented at the municipal or city level are downspout disconnections. Incentive programs are being introduced to encourage home-owners to disconnect their downspout from the storm (or combined) sewer system (McKenzie-Mohr et. al.). This reduces the stormwater volume that travels from rooftops to municipal pipes, storage tanks, and/or other related infrastructure; however, it does not allow for reuse of the water as it either infiltrates into the ground or becomes runoff that is captured by catch basins.

2.2 Drought Tolerance

The other side of the coin in water harvesting is the ability to save water for times of low rainfall or drought. The threat of drought has been managed through the exploration of alternative technologies, namely desalination, as well as groundwater recharging or water storage. For example, California has been practicing groundwater recharge since the 1970's wherein treated recycled water is injected into aquifers to prevent salt water intrusion and contribute potable ground water supply (EPA). Moreover, consideration of desalination as a primary water supply has become a reality in places such as Australia and South Africa. Ontario Teachers' Pension Plan and Hastings Funds Management invested in a 50-year lease of the Sydney Desalination Plant (SDP) in 2012 (Ontario Teachers' Pension Plan, 2012) under the premise of drought risk management. However, subsequent storms in the area have challenged its usefulness and the significant energy costs associated with the technology are also subject to climate risk due to the water-energy nexus. This means that large energy demands still contribute to climate change and the reliability of energy sources is vulnerable to the effects of climate change, demonstrating the shortcomings of placing heavy reliance on this technology. Therefore, we need to start looking towards solutions for water scarcity that are less energy intensive and able to be managed at the local scale.

2.3 Climate change adaptation and decentralisation

Cities have before them a challenge to adapt to climate change that reflects their organic evolution of land use development, wastewater management, and drainage of surface waters and rainfall. As cities traditionally evolve, they strain to maintain the piped drainage, sewage wastewater management and stormwater management functions facilitating public health, economic growth and eventually ecosystem protection. Paradoxically, that very growth they pursue strains the infrastructure. Into that equation we add the complexities of climate change which stresses the designed capacity of centralized water and wastewater infrastructure because that infrastructure is a hard, capital intensive response to a variable set of pre-climatic conditions. Nowhere is this more evident than in terms of managing stormwater and drought conditions. Moving water is energy intensive and complicated with most cities dedicating on average of 40-60% of their total electrical energy use to that task. Solving water challenges by pumping water from one location to another shifts the issue at hand from one of water use to electricity use. To address this, we need to reduce the reliance on centralized infrastructure. By supporting centralized infrastructure with distributed infrastructure, we can become more efficient with water management, capturing the water where it falls. Climate change will impose significant costs on municipal water utilities in years to come.

One solution they have at their disposal to support their actions to counter this trend is the application of smart and decentralized infrastructure on private properties, where utilities have not typically operated. As distributed intelligent rain harvesting penetrates a community there are two significant outcomes: 1) a decline in stormwater flows from the retention of rooftop runoff, and 2) an increase in uses to which that captive water is applied to the water cycle in the utility service area. The captured water can be applied to one of three demand management needs: 1) potable water offsetting for either potable or non-potable uses such as toilet flushing, irrigation, cooling tower water laundry or, after treatment, drinking water; 2) groundwater recharge for desalination, aquifer recharge and environmental flows; or 3) reentering into the sewerage system at a later time for water balance requirements of sewage treatment facilities.

2.4 Smart data on a micro-scale

Localized micro-climate data (rainfall, temperature, barometric pressure, humidity) is nothing new, but the typical distribution of weather stations to capture this data is highly variable. As cities become more dependent on data to plan for resilience and adaptation capacity, microclimate data at the household (or lot) scale becomes more and more important to ensure that forecasts are relevant for the areas of concern. The integration of smart water management enables a whole-city approach to infrastructure that not only enhances the range of operational facilities, but which generates significant data for water utilities, weather bureaus, municipalities, insurance companies, builders and more. In addition, by making real-time climate data and rainfall available for the community, households can see in real-time how much water they are using and storing, and can adapt their usage patterns to suit their needs. In the future, utilities may move towards credit people with the management of stormwater on their private property, creating community utilities, where individual homeowners share the responsibility for the solution.

3. Smart Water Solution

3.1 How Stormwater Smartgrids created reliable, measurable and efficient residential rain harvesting

3.1.1 Origins of a Residential Stormwater Smartgrid

RainGrid, and its Stormwater Smartgrid Utility Technology, evolved from the brain-trust of two seasoned water professionals: one a non-profit/social enterprise advocate who designed social marketing for residential rain barrel programs and who manufactured a purpose-built cistern for North American municipal stormwater management low impact development (LID) programs; the other an engineer who designed and managed conventional pipe and pond stormwater infrastructure for the land development industry and the municipalities who inherited that legacy infrastructure. Each saw the limitations of their contribution to solving the stormwater problem plaguing cities, and the technological, ecological, fiscal and social deficiencies that stood in the way of progressing past the existing paradigm in the face of climate change.

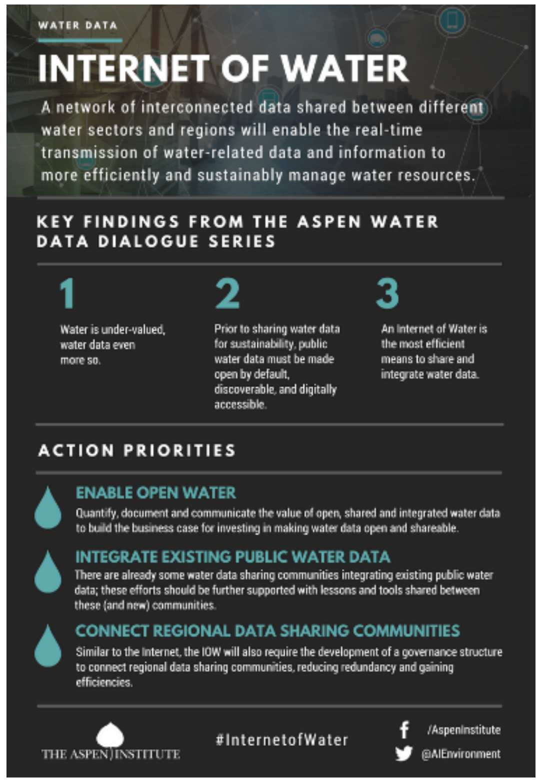

Figure 2. Internet of Water (Aspen Institute)

What attracted the stormwater engineer was the value added that smart distributed infrastructure represented as the missing piece in the land developer/municipal arsenal of coping with increasingly variable stormwater impacts, while the non-profit advocate saw AI/IoT technology as the solution to the social engagement barrier, represented by the reliance on property owner engagement and maintenance responsibilities, that minimized the legitimacy and use of passive distributed stormwater infrastructure.

The RainGrid founders not only acknowledged there exists a disconnect between the performance outcomes anticipated, and the restrictions that a traditional municipal stormwater business model delivered but that without a wholesale technological and business model restructuring, municipalities, land developers and stormwater utilities would be trapped in a negative feedback loop of building greater quantities of pipe conveyance, public land LID and end of pipe treatment facilities as their landscape became more impermeable and densely developed. While the might eliminate combined sewer overflows, non-point source contaminated stormwater impacts would magnify.

The typical municipal stormwater utility business model does not include private property as the basis of its asset management regime. That planning cycle begins and ends with the collection, conveyance and treatment plan. Although some municipalities such as Philadelphia, PA have encouraged the application of privately purchased and operated LID on commercial properties through subsidy programs, they still refuse to expand their reach into the residential sphere. (Philadephia Water Department, 2018) The Green Acres Program offers $5 million each year in stormwater grants to provide non-residential PWD customers with financial incentives to manage stormwater runoff with the added incentive of reducing their stormwater bill. In the second year of the program, PWD awarded $4.7 million to 17 projects that will capture runoff totalling 77 greened acres. Non-residential customers in Special Services Districts can also apply collectively for additional funding through Business Improvement District Grants. This lack of residential property engagement largely reflects a limited capacity in public engagement and a reticence in adopting distributing infrastructure based on its terrible record for operation and maintenance.

Residential properties do however represent an average of 45-57% of gross impermeable area in the average city as the below table illustrates for a typical low-rise suburban development.

Table 1. Gross impermeable area analysis of a typical low rise subdivision (RainGrid 2014)

Example 1 - Low Density Green Field Subdivision					
Total Area Assumed	40ha				
Total imperviousness, averages 45% broken down as follows:					
Type of Use	**% Subdivision**	**% Impervious**	**Impervious Area (ha)**	**Pervious Area (ha)**	**Total Area (ha)**
Park	5	0	0	2	2
Road (incl sidewalks)	17	75	5.1	1.7	6.8
Commercial/Institutional	5%				
Commercial Roofs	2	100	0.8	0	0.8
Commercial Parking	2.5	100	1	0	1
Commercial Yards	0.5	0	0	0.2	0.2
Residential Lots:	73%				
Houses & Sheds	25.55	100	10.22	0	10.22
Res Driveways	5.475	100	2.19	0	2.19
Res Yards	41.975	0	0	16.79	16.79
TOTAL			19.31	20.69	40
Total imperviousness: 0.48275 (fairly close to predicted 45%)					
What can be controlled by RSSUT (residential + commercial): 11.02ha is equal to a little more than half of the impervious area (57%)					
SWM Designer's context					
Only the 2 year storm could realistically be captured					
The overall storage per impervious hectare is 218.3m3					
The overall storage per hectare of subdivision is 105.4m3					

The recent evolution of affordable and reliable AI and IoT applications have facilitated the transformation and easier adoption of one of the most intractable challenges facing urban stormwater – residential rain harvesting and reuse for flood and drought resilience on previously unmanaged private properties.

3.1.2 AI/IoT Innovation For Distributed Infrastructure: Stormwater Smartgrid Utility Technology

Residential Stormwater Smartgrid Utility Technology (RSSUT) builds an AI cloud-managed, Internet of Things (IoT) operationally connected lot-level stormwater harvesting infrastructure for reliable, measureable and effective flood and drought adaptation by residential properties. By bringing AI and IoT to individual property rooftop runoff harvesting, cities can adapt to climate variable stormwater management objectives at a significantly lower capital and operating costs (CAPEX/OPEX) than by expanding the capacity, operation and maintenance of conveyance and treatment infrastructure.

A community-based Stormwater Smartgrid utility infrastructure is built upon the years of research and innovation associated with the benefits of implementing distributed green infrastructure. Add AI/IoT networking capabilities to otherwise passive GI transforms those methods into proactive, utility-scalable, asset-managed municipal stormwater management infrastructure for climate adaptation. An RSSUT system delivers stormwater management at significantly lower capital cost per litre retained, at a fraction of the time required for conventional solutions such as sewer or retention pond retrofitting, and delivers cost-effective and space-efficient LID. Capable of effectively taking rooftops 'offline' from the minor storm system, neighbourhood Stormwater Smartgrid networks transform passively operated, unmeasurable and rarely maintained municipal voluntary rain barrel programs, into a measureable, reliable and effective community utility asset-managed infrastructure.

RainGrid offers real-time rainfall/diversion data visualisation and micro-climate analytics on an individual property and network wide aggregation. Data streams can be analyse to provide municipalities with advanced monitoring and event analytics to improve resilience planning and the infrastructure maintenance.

Whether applied as a residential groundwater recharging strategy or as a potable demand efficiency offset, residential Stormwater Smartgrid complements source water protection, and improved water quality. Meanwhile, system users gain access to potable water offset volumes for exterior irrigation or interior envelope (household) non-potable use.

Direct real-time information on stormwater flow diversion and use offers a distinctive opportunity for engagement with property owners in real-time on climate adaptation, stormwater and potable water efficiency. This direct line of communication to user's smartphones of desktops offers a personalised engagement portal for their engagement with the municipality owned infrastructure located on their property, filling a gap that stormwater education programs have long aimed to have with communities.

3.2 RainGrid Stormwater Smartgrid System Design and AI/IoT Architecture

RainGrid's Residential Stormwater Smartgrid Utility Technology (RSSUT) is a smart water management technology designed to capture rain runoff from rooftops that otherwise flows unregulated across properties and which constitutes the majority of contaminated stormwater discharge from residential and commercial properties.

The RainGrid system consists of: individual property cisterns, an artificial intelligent cloud-based weather algorithm, localized sensors, and electrically actuated drainage for harvested water reuse either within or exterior to the building envelope. A basic RainGrid System offers two stage primary filtration and storage in either above or below ground cisterns.

A Stormwater Smartgrid System has the primary goal of taking rooftops offline from the storm sewer system, with a secondary goal of providing harvested water for one of three use demand management conditions:

a. Groundwater recharge or sewer system flow balancing
b. Potable water offsets for exterior irrigation
C. Potable water offsets for interior envelope non-potable uses, or post-treatment potable replacement

The third goal of the RainGrid system is micro-climate data visualization and analytics. The system harvests environmental and operational data from its algorithmic analysis of real-time rain fall runoff, real-time capture, real-time use, and real time discharge in six minute intervals.

3.2.1 The Stormwater Engineering

The basic focus of Stormwater Smartgrids is to address the majority of imperious surface runoff in urban neighbourhoods. As the table below illustrates, residential housing rooftops represent the largest individual percentage of impermeable area.

Low Density Green Field Subdivision
Total Area Assumed: 40 ha
Total imperviousness, averages 45% broken down as follows:

Table 2. Low Density Green Field Subdivision

Type of Use	% of Subdivision	% Impervious	Impervious Area (ha)	Pervious Area (ha)	Total Area (ha)
Park	5	0	0	2	2
Road (incl sidewalks)	17	75	5.1	1.7	6.8
Commercial/Institutional	5%				
Roofs	**2**	**100**	**0.8**	**0**	**0.8**
Parking	2.5	100	1	0	1
Yards	0.5	0	0	0.2	0.2
Residential Lots:	73%				
Residential Rooftops					
Houses & Sheds	**25.55**	**100**	**10.22**	**0**	**10.22**
Residential Driveways	5.475	100	2.19	0	2.19
Residential Yards	41.975	0	0	16.79	16.79
Total			19.31	20.69	40

Total residential (10.22 ha) and commercial (0.8 ha) roof area impervious -=11.02 ha
Total imperviousness: 0.48275/48.27% of gross area and rooftops represent: 57% of impervious.

For this scenario, we presume that the average household has roughly 1300ft2/120.77m^2 of roof area. For this size of property, a 1.3'/33.2mm rainfall would generate 39.6m3 of rooftop runoff. Presuming a RainGrid Stormwater Smartgrid cistern with 1800ft3/50.97m3 of storage on every property, we would be capable of sufficiently managing 99% of all annual rain events with a return frequency capable of managing cascading wet weather events.

3.2.2 Regulatory Framework

Regulatory frameworks vary widely but virtually all stormwater regulatory regimes are tending toward the 90% rule in their application of runoff reduction. In Ontario, the Lake Simcoe Region Conservation Authority, for example, requires land developers to create stormwater BMPs for new non-linear & redevelopment lands that retain the first 25 mm from impervious surfaces.
Linear Development, greater of:
The first 12.5 mm of runoff from new or fully reconstructed
The first 25 mm of runoff from the net increase in impervious area

Flexible (restricted sites):
1. Min 12.5 mm & 75% annual TP load reduction
2. Maximum extent practical of volume reduction & 60% annual total phosphorus load reduction
3. Off-site treatment requires the use of LIDs

In this scenario, Residential Stormwater Smartgrid cisterns would effectively take the property rooftop offline from the storm sewer system, and significantly reduce or potentially eliminate the need for an end-of-pipe pond systems.

3.3 RainGrid Stormwater Smartgrid Design

Stormwater Smartgrid systems provide operational interfaces for individual property owners and network administrators through one of two data visualization and analytics dashboards.

3.3.1 AI/IoT System Architecture

The RainGrid Residential Stormwater Smartgrid Utility Technology is a basic Ai/IoT infrastructure consisting of three basic parts:

1- A quantitative precipitation algorithm (AI) using Environment Canada or NOAA raw weather data correlated to address, roof area and cistern volume

2 - An IoT controller operating sensors for temperature, barometric pressure, and cistern level, and an electrically actuated valve for drainage (and where installed a pump)

3 - Individual unit operational and data visualization dashboards <my.raingrid.com> and administrative operational command and control dashboards <manage.raingrid.com>

The system architecture is illustrated in the following diagram, which represents data flows of the intelligent cistern on a network basis.

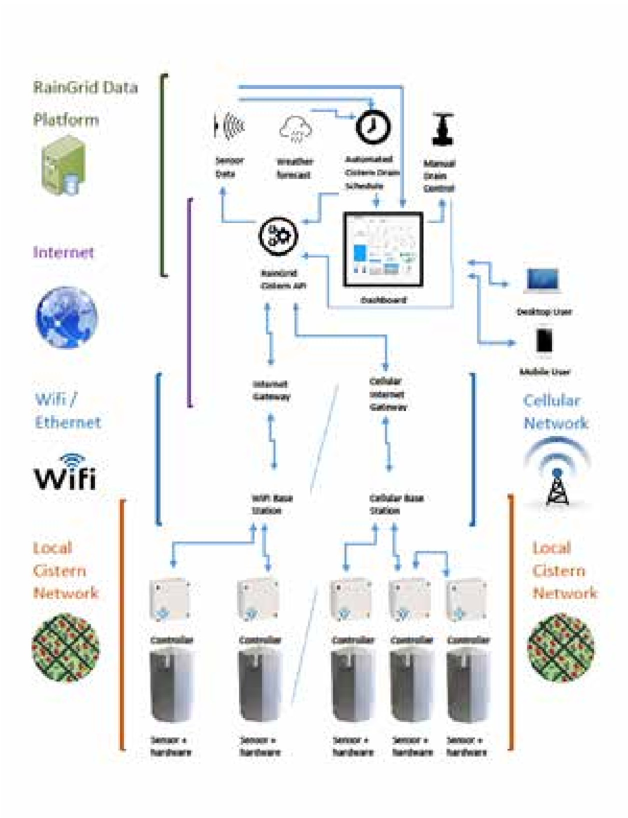

Figure 3. RainGrid Stormwater Smartgrid Architecture

3.3.2 Network Structure

Each Stormwater Smartgrid cistern has a level sensor comprising either an ultrasonic or pressure transducer sensor linked to an RSSUT controller. The controller communicates data through the household modem/router by means of either a Power over Ethernet (PoE) cabled connection, or an AC powered wireless connection.

For a greenfield subdivision, a Stormwater Smartgrid network structure can be installed in

concert with the ISP service to the home from the internet gateway servicing the development via the fibre or coaxial cable.

3.3.3. Residential UI/UX Dashboards

The individual residential property dashboard <my.raingrid.com> consists of the following visualizations on two pages:

Operational Overview

a. A cistern graphic illustrates degrees of available storage (i.e., 0% is full and 100% is empty).

b. A valve graphic illustrates whether the valve is open, intermediate or closed.

c. A five day predictive weather forecast illustrates temperature, barometric pressure, predicted precipitation, and algorithmic predictions of the cistern's electrically actuated (EA) drain valve operation, and percentages of volume to be drained in correlation to predicted rainfall, and runoff top runoff relative to the cistern's existing available storage capacity.

d. A stormwater diversion graphic of weekly, monthly and annual cistern capture.

e. A numeric graphic of real-time cistern controller location, temperature and barometric pressure.

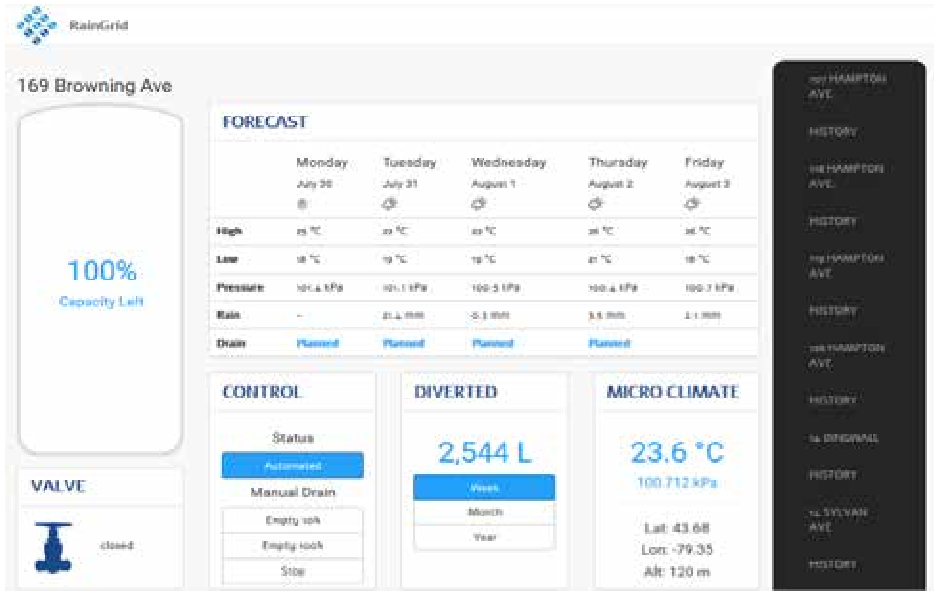

Figure 4. Residential Cistern Dashboard #1

Historic Graphical Overview: three graphs illustrates real-time operational histories

a. Total Diversion and Real-time Storage: a three axis graph showing a solid line for cumulative stormwater diversion by the cistern, and a histogram of the actual real-time storage volumes in the cistern available in one hour, three hour, one day, three day, one week, one month, and nine month periods.

b. Micro-climate: a three axis graph of temperature and barometric pressure in real-time over one hour, three hour, one day, three day, one week, one month, and nine month periods.

c. Diversion Rate: a thirty day analysis of runoff capture and bypass.

Figure 5. Residential Cistern Dashboard #2

3.3.4 Residential Network Administrator UI/UX Dashboards

The **<manage.raingrid.com>** network administrators' dashboard consists of ten individual system and network operational data visualization and analytics dashboards:

1. System – an overview of the primary operational conditions of each property by: Address, Last Sync Date, Cistern Fullness, Valve Status, Temperature, Sensor Pressure, System Voltage, and System Current
2. Map - google maps of the locations of the RainGrid systems
3. Reports – data reports of diversion, use and other variables for each individual cistern location
4. Filter Data – correction of data anomalies
5. Test – diagnostic assessment of individual cistern operations
6. Provisioning – set up for individual cistern operations
7. Users – project access users
8. Regions – groupings of cisterns by either locale or system type or both
9. Administrators – permissions for administrative control by Region, Region Administrator, Provisioning or Read Only Access
10. Options – password and access changes

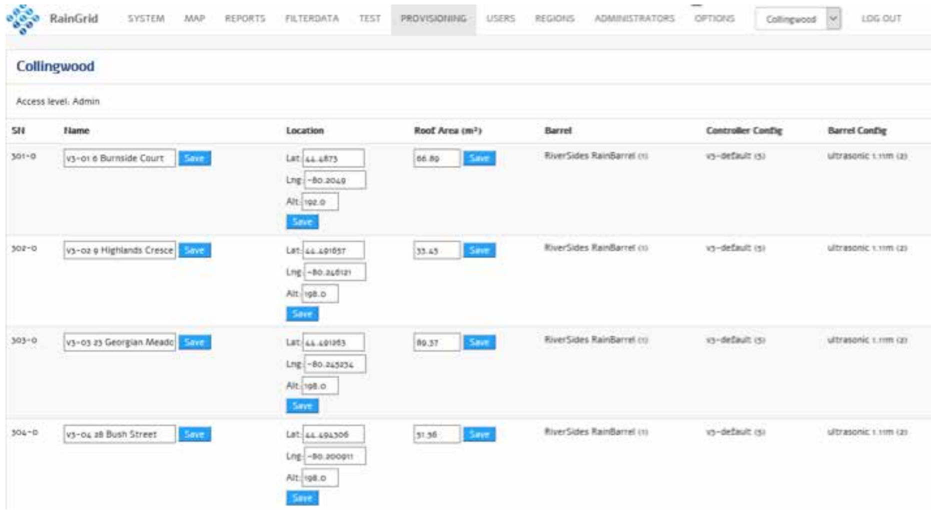

Figure 6. Collingwood 3.0 Smart Stormwater Pilot Project (Provisioning)

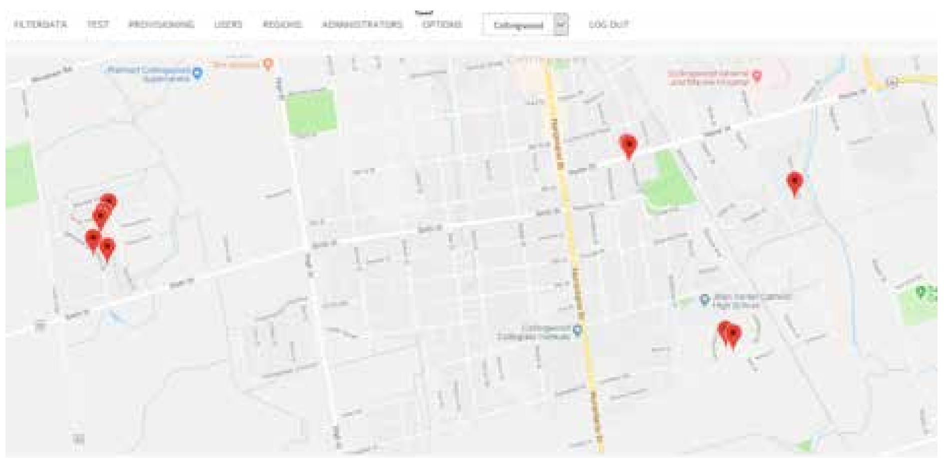

Figure 7. Collingwood 3.0 Smart Stormwater Pilot Project (Map)

3.3.5 Cistern Design

In addition to real-time controller design and development, RainGrid undertakes research into residential cistern design. Cistern design is essential to the success of implementing smart rain harvesting for both greenfield home builders and existing home retrofit implementation. The objective is to create cisterns that integrate well with real-time automation, that require minimal maintenance, and that seamlessly integrate rain harvesting into the home, not dissimilar to any other utility service.

To meet its promise of reducing or eliminating the costs of end-of-pipe pond demands for land, materials for piped conveyance and regular maintenance, residential rain harvesting must by design and practice offer reliable, effective and measurable results. This begins by designing a controller that integrates well with existing cistern design or designing OEM cisterns that address the highly variable needs of retrofit and greenfield applications.

3.3.6 RainGrid Smart Cisterns

A Stormwater Smartgrid system effectively reduces 90%+ of rooftop runoff depending on the size of the cistern serving the roof area, or the storage capacity of the rooftop for a smartBlu Roof system. Because the algorithm of a stormwater smartgird is capable of predictive and real-time weather analytics it that correlate rainfall volume intensities to rooftop area and cistern capacity. In this regard, we can store runoff in less space than before because we can fully discharge to ensure full rooftop runoff capture..

In aggregate terms, a fully functional Stormwater Smartgrid, operating on a lot by lot basis in either residential or commercial property configurations, is capable of retaining roughly 60% of all urban runoff as system penetration rises from 20-80%.

Figure 8. Stormwater Smartgrid cistern

Table 3. Estimated scalable cost of residential RaidGrid Stormwater Smartgrid Utility Technology (RSSUT) showing economies of scale (System for a 100m² roof area, 3000 litres cistern, US dollars)

Costs	1 system	500 systems	1000 systems	5000 systems
Cistern Incl. filtration, quietening inflow	$1500	$1300	$1000	$1000
Collection piping	$300	$200	$150	$100
Electrically Actuated Pump & Valve	$800	$500	$400	$400
RSSUT including US or PT sensor(s)	$1600	$1000	$600	$400
Total Cost	$4200	$3000	$2150	$1900

CASE STUDIES
COMMUNITY-BASED STORMWATER SMARTGRIDS: DISTRIBUTED AI/IOT RAIN HARVESTING NETWORKS FOR FLOOD AND DROUGHT RESILIENCE

The costs associated with Stormwater Smartgrid technology applications vary widely between whether they are applied on a utility asset managed basis or within the voluntary property owned context. New built single family residential properties can be fitted with AI/IoT managed subterranean cisterns sized to match the roof area on the basis of eliminating 90%+ flows. This figure reflects the reality that it is impossible to size a cistern to manage 100% of flows since 100+ year storm events cannot be predicted. A standardized configuration for 5,000-10,000/ gallons would be $2500.

3.3.7 UI/UX Data Visualization

Each RainGrid User has a perfect window on their home's micro-climate conditions thanks to the Stormwater Smartgrid IoT cistern's 5 day predictive weather algorithm, volume/flow sensors, and electrically actuated drain valves, wirelessly linked to their home internet connection. Individual property users have access to their RSSUT data and operations through <my.raingrid.com> an interactive desktop or mobile data interface providing visualization of specific property microclimate and cistern operations, cistern water use control, and a VPN platform for messaging. The dashboard provides real-time operational status visualization of their Stormwater Smartgrid cisterns consisting of the 5 day predicted rainfall which indicates and any automated drainage events for their cistern, detailed insights into their cistern's operation while also providing manual operational access to thousands of litres of diverted rooftop runoff.

The residential data visualization platform <my.raingrid.com> visualizes in fifteen minute increments of 30 second real-time data, six month to one hour graphs of household stormwater diversion and use, and temperature and barometric pressure.

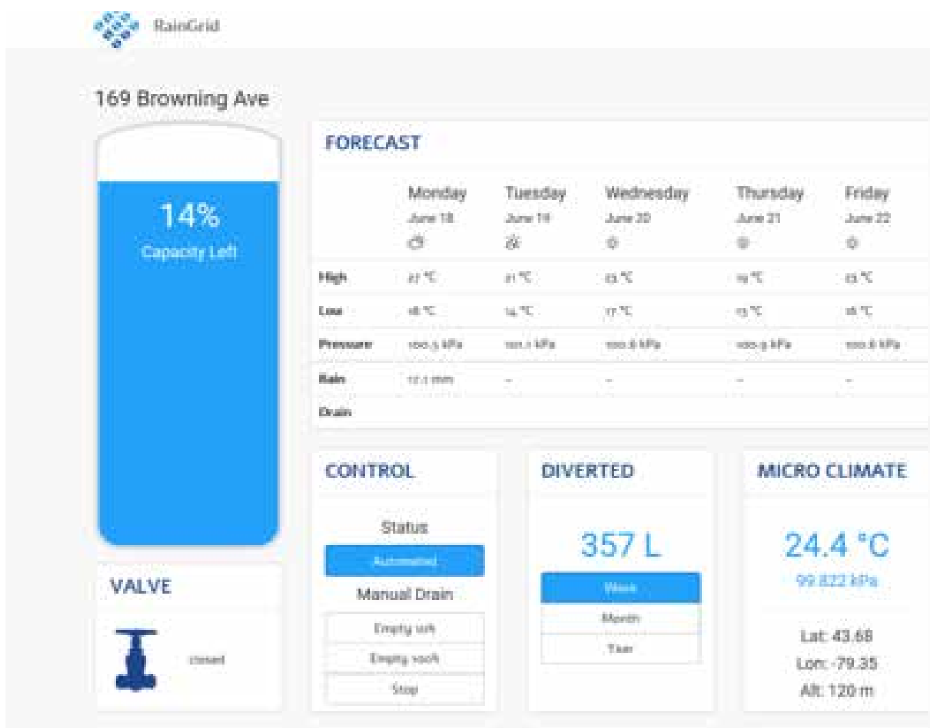

Figure 9. My.raingrid.com Residential Data Visualization›

The data visualization UI/UX ***<manage.raingrid.com>*** – is a comprehensive network administrative backend consisting of: a list of property addresses & cisterns, a Google map by address and GIS coordinates (capable of integrating municipal sewershed GIS layers), a property list of individual cistern component status and fault alerts, stormwater diversion & potable water offset data visualization by individual and/or network properties, administrative management protocols and access designations, ability to establish sub-networks by community boundaries, postal code or other characteristics.

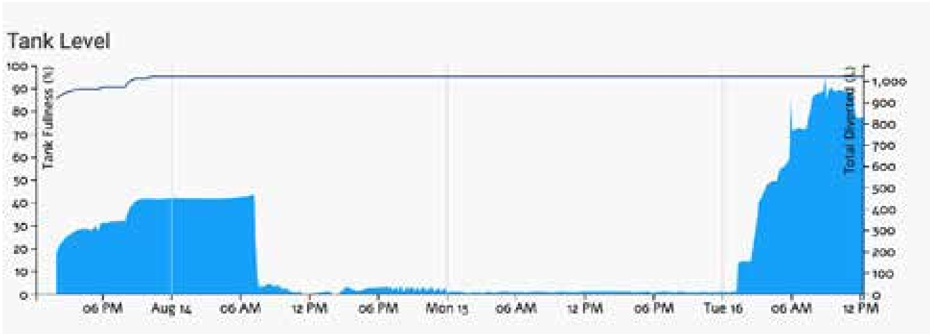

Figure 10. Automated draining capacity based on predicted rainfall (Source: RainGrid)

Figure 10 shows the smart cistern automatically draining the barrel in anticipation of rain. You can see this in the graph shortly after 7am on August 14, when the barrel emptied to around 15% capacity. The barrel begins to fill again on August 16 at 2am, filling first to about 15%, then continuing to fill the barrel to 70% of its capacity. After another short pause in the rain, the barrel fills to 90% just before 12 p.m. The administrator then drained the cistern by a 10% to allow for a 25% capacity for future collections.

Community-based distributed Stormwater Smartgrid utilities, along with smartBlu Roofs, create property-based flood and drought adaptation. Stormwater Smartgrids convert rainfall into a secure water capacity for either individual property or community wide applications, while contributing a degree of climate flood resilience for localized and downstream communities. Private property-based AI/IoT rain harvesting for reuse and/or groundwater recharge is a transformative water security of supply infrastructure offsetting and complementing insecure water and wastewater supply infrastructure. AI/IoT offers highly valuable climate resilience, conservation, demand and/or ecosystem recharge offset data visualization and analytics for water utilities and users.

Private property or institutional distributed AI/IoT rain harvesting is a powerful tool for utilities seeking to meet the baseline goals of SDGs 6.3 to improve water quality by halving the proportion of untreated wastewater, and substantially increasing recycling and safe re-use; and 6.4: to increase water efficiency, ensure sustainable withdrawals and supply of fresh water, and substantially reduce water scarcity.

AI/IoT rain harvesting provides three key climate de-risking modules:
1) Attenuation of stormwater-related chronic (permeability coefficient determined) and seasonal (room for water determined) snow melt, monsoon or wet season peak runoff flood impacts; minor overland flood and sewer system surcharging management.

2) Offset potable water security of supply where variable conditions [restricted/seasonal ground or surface water supply, restricted pump energy, decrepit (non-revenue water leakage or theft) infrastructure] reduces security of supply; or as an ecosystem recharge and drought resilience for sewage infrastructure.

3) Real-time data visualization data and decision-making analytics of micro-climate weather, localized stormwater runoff capture, diversion, and post-harvesting use, and pre-weather event cistern/rooftop storage operations and management. (Real-time micro climate data management).

This three-tiered benefits structure of Stormwater Smartgrid networks reflects a convergence of AI/IoT-enabled rain harvesting with smart cities strategies, One Water (U.S. Water Alliance, 2018) infrastructure policies, ecosystem protection regulation mandates, community knowledge and resource capacity building, and climate resilience/adaptation; the baseline water elements of the SDGs. Stormwater Smartgrids reflect a delineation of AI as the data interpretive and analytical brain fitted to the IoT operational body of real-time rain harvesting (Kranz, Maciej, Vice President, Corporate Strategic Innovation Group, Cisco Systems, 2017). A Stormwater Smartgrid, like an energy smartgrid, utilizes otherwise isolated distributed rain harvesting. It does so by applying AI analytics (quantitative precipitation forecast algorithms) to the operational automation of IoT managed rain harvesting (for any of the three operational outcomes identified above), which in turn generates property-and city wide data on rainfall, rainwater use, offsets, community engagement (via data and utility communications) linked to the attainment of SDG goals on a local and regional scale.

Building upon this foundational research work RainGrid and a few other utilities and companies globally have pursued AI/IoT stormwater harvesting to resolve two primary social and administrative challenges facing the use of distributed stormwater harvesting on private property: 1) operations and maintenance by the property owners, and 2) the operational reliability, data measurability and operational effectiveness of those cisterns.

The Stormwater Smartgrids are municipality owned on the owner's property – CBP3 (community based public private partnerships) – a rapidly evolving mechanism for the implementation of distributed infrastructure on private property.

Microclimate data
Stormwater Smartgrids also collect detailed 30-second data of rainfall and its intensity. This allows us to make rain maps of the city that detail when and how much it flowed, and where; the actual weather, not a forecast. Over time, this facility will be able to do two very important things – it will be able to cross reference past weather events with predicted weather, and via the weather artificial intelligence (AI) make a detailed analysis of the likelihood that a forecast will actually be realized. Further, it will be able to track climate change dynamics by comparing current to past weather events on a granularity not hitherto available.

3.4 Stormwater Smartgrid Pilot Projects

3.4.1 Oakville, Ontario 2015

RainGrid launched its 2015 Stormwater Smartgrid 1.0 prototype pilot in Oakville, Ontario which successfully demonstrated how a retrofitted RainGrid V1 500 cistern can function to automatically divert runoff from storm sewers during rain events and automatically release stored water prior to subsequent storms. The pilot stored runoff from one downspout draining ¼ of a 1,200 ft.2 detached home rooftop to a 500L cistern, from June-October 2015. In an average rain year, the cistern diverted and detained 14,129L of rain, which was recharged to groundwater via passive irrigation. The automated valve coupled with
RainGrid's quantitative precipitation forecast algorithm automatically drained the cistern 24 hours prior to predicted rainfall to ensure maximum storage capacity.

RainGrid launched its Stormwater Smartgrid 1.0 prototype pilot in Oakville, Ontario in 2015 on one suburban home to test the proof of concept. The original design challenge was to determine how to automate a residential rain barrel. The prototype consisted of a hand built IoT controller consisting of a Texas Instruments development board, with ports for the sensor, electrical valve, and Power over Ethernet (PoE) injector. The PoE cable connected to the household router via a PoE injector linking the controller to a cloud-based server integrated with real-time weather data prediction AI algorithm . The controller operated a pressure transducer sensor and an electrically actuated drain valve connected to the AI cloud via a power-over-ethernet (PoE) controller. The controller and peripherals were fitted to an HDPE 500L RainGrid V1 above ground retrofit cistern. The AI measured the volume of the cistern relative to the volume of the predicted rainfall and subsequent rooftop runoff. The AI measured the cistern volume and determined if storage was adequate to store predicted runoff. If the AI calculates rain event runoff volumes greater than available storage in the V1 500L cistern, the AI directs the controller to open an electrically actuated drain valve until such time as the sensor determines the necessary storage capacity is available.

The pilot cistern stored runoff from one downspout draining ¼ of a 1,200 ft2 ($28m^2$) detached home rooftop to a 500L cistern, from June-October 2015. In what was an average rain year, the cistern diverted and detained 14,129L of rain, which was recharged to groundwater via passive irrigation. The AI quantitative precipitation forecast (QPF) algorithm converted raw weather data from Weather Underground automatically drained the cistern 24 hours prior to predicted rainfall to ensure maximum storage capacity.

3.4.2 Toronto, 2016

RainGrid embarked upon its 2.0 Stormwater Smartgrid Utility Technology development and implementation in 2016 by successfully building a research and development partnership with George Brown College's Office of Research and Innovation and its School of Mechanical Engineering Technologies and Advanced Prototyping Lab. GBC ORI secured funding support from the Natural Sciences and Engineering Research Council of Canada (NSERC) Green Home program to develop and build RSSUT 2.0 prototypes for the Toronto RainCAP pilot project. A National Science Engineering and Research Council's (NSERC) Green Homes program grant of $35,000 offset the costs to design and assemble 25 2.0 RSSUT systems.

The 2.0 Stormwater Smartgrid Smart Cistern controller switched from a PoE communications and power platform to a wireless solar recharged DC power platform using Zigbee X wireless transmission to a household IoT router. The same Measurement Specialties pressure transducer sensor and electrically actuated valve from the 1.0 prototype were used in this project. The original UI/UX operational visualization and analytics dashboard was significantly upgraded to comprise two UI/UX platforms, one residential, the other administrative. These were:

i)https://my.raingrid.com – desktop-based residential web interface giving property specific microclimate and operational data, cistern water use control, and a VPN platform for messaging), and
ii) https://manage.raingrid.com – a comprehensive administrative backend consisting of: network property & cisterns list, Google map by address and GIS coordinates (capable of integrating municipal sewershed GIS layers), individual cistern and property component status and fault alerts, stormwater diversion & potable water offset data visualization by individual and/or network properties, administrative management protocols and access designations, ability to establish sub-networks by community boundaries, postal code or other characteristics.

Neither site was optimized for mobile or linked to a native app for installation. Participants entered their logon charactersistics for their internet into the my.raingrid.com interface which thereafter auto entered the logon data for their router with every opening of the interface.

Coupled with that development partnership was a successful application by RainGrid to the Commission for Environmental Cooperation's North American Program for Environmental Community Action (CEC-NAPECA). However, as NAPECA funding is only granted to community organizations, RainGrid transferred funding to a local community organization to deliver the project in the Riverdale neighbourhood.

The average residential use of rainwater harvested by the Toronto 2.0 Riverdale pilot project was difficult to calculate due to the technical difficulties of the system. Data from individual systems varied greatly but the 500L cistern systems retained an average for use or recharge in one year of 195,927L.

3.4.3 Riverdale, 2016

In 2016, RiverSides (an independent group) installed and tested 15 of RainGrid's AI/IoT cisterns in the Toronto community of Riverdale. As part of the pilot 15 RainGrid Inc. controller systems were purchased and installed with 500-liter cisterns, located on the properties of 15 participating householders. The following section details the results and lessons learned from this pilot.

Figure 11. Installation of RSSUT system in the Riverdale pilot (Source: Riversides)

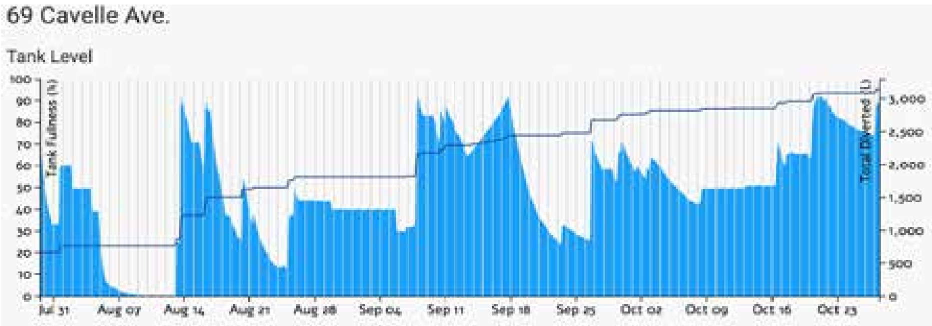

Figure 12. Rainfall collection, tank-level and water-use/drainage metrics for Household 4 (August 28 – October 28)

Table 4. Results and projected water saving estimates from five of the fifteen pilot houses

Pilot details	House 1	House 2	House 3	House 4	House 5
Cistern size	500L	500L	500L	500L	500L
Roof surface	28m²	46.5m²	46.5m²	27m²	28m²
Projected annual stormwater collection estimate*	14,000L	18,400L	20,000L	10,400L	18, 500L
Data collection duration	5 months	5 months	5 months	5 months	3.5 months
Average verifiable monthly collection	1,000L	1,440L	1,500L	650L	1,720L
Ave. monthly collection estimate	1,400L	1,840L	2,000L	1,040L	1,850L
Total verifiable stormwater collected, stored and diverted from storm sewers	5,000L	7,200L	7,505L	3,249L	6,023L
Total estimated stormwater collected, stored and diverted from storm sewers	7,000L	9,200L	10,000L	5,200L	6,500L
Amount of collected water used on garden	80% (~4,000L)	0%	80% (~6,000L)	100% (~3,250L)	80% (~5,200L)
Estimated amount of stormwater infiltrated on property	7,000L	9,200L	10,000L	3,250L	6,023L

*Based on 10-month season

While each household in the pilot was provided with the same size cistern (500L), roof size variability, along with other issues detailed below (e.g. high flows, maintenance and internet connection) resulted in a high variability in results for the annual projection for stormwater collection (from 10,400 – 20,000L per year). Despite this, each participating household was able to divert a minimum of 3,249L per month of stormwater, which was used between 80-100% for garden maintenance, reducing the use of potable water required for garden care.

3.4.5 Key lessons learned in this project

Lesson 1 – It was discovered that the system can be limited in storms, as the high low volumes can become turbulent when entering into the downspouts, which can overwhelm the diverter box and the overflow diverter box, leading to a significant reduction in the verifiable volume of stormwater collected, stored and therefore available for the homeowner. To rectify this issue, Riversides custom designed a 'storm funnel', which connects the downspout to the diverter box. This approach focuses the rainwater directly into the diverter value, largely eliminating the overflow issue and more than doubling capture rates.

Figure 13. Riverside Storm funnel in diverter box (left); uninstalled storm funnels (black) and diverter box (green) with filter (white)

2. Secure internet connectivity is essential for ensuring the cistern can function as a 'smart' tool, instead of just as a raintank. When connection is lost the control of the water capacity and storage, and the data-collection opportunities are also lost. This is particularly important for anyone who turns their electricity/internet off when going on away for any period of time. To address this issue, a wireless system and internet service must be considered to ensure the system is not dependent on the homeowner's internet.

3. Manual maintenance is still required to ensure the stormwater smartgrid can function to its highest capacity. For example, clogged filters and storm-surge overflow can result in significant missed collection opportunities. By installing a storm funnel, preparing with early-season filter maintenance and sending automated updates to the customer when a filter appears to bot be working to its full capacity, this issue should be reduced.

Figures 14 and 15 below demonstrates the difference that cleaning of the filters can make to the success of the collection rates. As shown in the graph, the collection rates in July, August and most of September (i.e. when the filters were clean) were very high. After September 18 a clogged filter resulted in a severe drop in collection efficiency.

Figure 14. Rain-fall collection, tank-level and water-use/drainage metrics for House 1 (July 30 – October 27, 2016) [Showing collection when filters are clean]

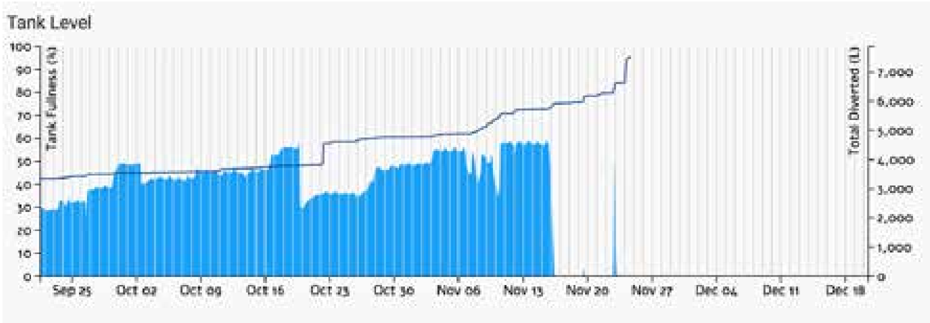

Figure 15. Rainfall-collection, tank-level, and water-use/drainage metrics for House 1 (September 20 – November 16) [Showing collection when filters are not clean]

As shown in Figure 15, collection rates after September 20 through to November 16 were approximately 20-30% that of when the filters were clean. This resulted in a loss of approximately 2,500L of stormwater that could have been collected over the September –November period, showing the importance of maintenance of the tools to ensure the smart element can function as designed.

Box 1. Design, Implementation, Maintenance, Analytics: Community Utility Business Model

Stormwater Smartgrids provide municipal or utility decision makers with intelligent distributed green stormwater infrastructure that seamlessly integrates as asset-managed infrastructure into stormwater runoff/flood or drought resilience prevention and response planning. Stormwater Smartgrid Utility Technology can be optimized and modified to meet a municipality's unique needs.

Tailored Design - RainGrid's highly-trained and knowledgeable staff guide you through a modular technical, regulatory and economic needs analysis tailored to present and future circumstances.

Turnkey Implementation - RainGrid builds community residential and business engagement models to facilitate rapid adoption and implementation. Turn-key installation or training of municipal/third party installation teams make it easy to sale up implementation.

Maintenance - Like any utility, Stormwater Smartgrids require regular maintenance to deliver optimal results, requiring training and maintenance from the team.

Analytics - The true power of the RSSUT lies in the endless opportunities for data collection, visualization and analytics. RainGrid provides cities with advanced analytics to help them better understand how much rain is falling, where, how it is changing over time, and how that may affect asset management planning. Customized analytics reports meet specific needs for planning of climate adaptation, sewer system design, and risk evaluation.

CASE STUDIES
COMMUNITY-BASED STORMWATER SMARTGRIDS: DISTRIBUTED AI/IOT RAIN HARVESTING NETWORKS FOR FLOOD AND DROUGHT RESILIENCE

4. Project Inputs

The original input to meeting the challenge of building a distributed network of smart rain harvesting has been a two decade long evolution of municipal residential rain barrel programs. These programs were originally designed to address the systemic design of urban combined sewer systems which collected stormwater in pipes designed to overflow specific wet weather volumes to natural water courses. During the lifetime of Stormwater Smartgrid, a lot of funding and research has been put into the project through numerous grants (e.g. The Green Acres Program as detailed above).

4.1 Enablers and Barriers

4.1.1 Enablers

There are numerous major enablers and barriers to IoT Stormwater Smartgrids but here are the top ones.

Innovation and investment platforms support
The greatest enabler for Stormwater Smartgrid has been the ongoing support from innovation programs and awards. Stormwater Smartgrid was selected for The Water Environment Research Foundation's *Leaders Innovation Forum for Technology Program* (WRF-LIFT) (Water Environment Research Foundation, 2018), which brings together the best scientific minds and industry specialists to accelerate adoption of innovative water technologies. LIFT is a multi-pronged initiative undertaken by WERF and Water Environment Federation (WEF) to help bring new water technology to the field quickly and efficiently. LIFT includes components such as Technology Evaluations, People and Policy, Communication and an Informal Forum for Research and Development to better serve the industry. Being selected for the LIFT program in 2015 was a significant boost to the legitimacy with water utilities of RainGrid, and an incentive to rebrand as Residential Stormwater Smartgrids Utility Technology to give a fuller understanding of the application.

In addition to this, WaterTAP Ontario has been a major supporter of RainGrid's technology and has provided corporate capacity to advance the comprehension and market exposure of RainGrid's distributed stormwater and intelligent rain harvesting.

RainGrid's selection for International Trade missions to water scarce regions of the United States, has also significantly benefitted RainGrid by increasing its profile in new markets, and potentially built partnerships with utilities seeing the opportunities for intelligent stormwater infrastructure on private property.

4.1.2 Barriers

The Public Private Divide
Probably no issue informs the barriers discussion about disturbed stormwater harvesting more than the split between the perception and application of publicly financed, owned and operated infrastructure than the division between private and public land.

There are no shortage of city building or water utility sponsored AI/IoT programs enabling public infrastructure - LED streetlights, smart water metering, leak detection, and numerous state of good repair programs.

Municipalities and water utilities state they cannot install infrastructure on private property, despite installing water meters and electricity meters. However due to the law known as 'eminent domain', the municipality can come in and build whatever they want to build for the 'greater good'. They would therefore be able to maintain the infrastructure. Despite this, municipalities and water utilities are hesitant to own infrastructure on private property, reducing the potential for the scale of implementation required (around 40% of households capturing their own rainwater) to make a real impact at a community level.

While municipalities and utilities would benefit from residential stormwater smartgrids through both reduced stormwater to manage and increased data availability, many may see decentralising stormwater management as dimishing their role in urban water management. Despite this, there is the potential for utilities to invest in this kind of infrastructure (managing the infrastructure themselves, instead of RainGrid managing it), which would ensure they maintained a strong role in the management of the water. This is what is often referred to as Community Based Private Public Partnerships, and could be the answer for households interested in using Stormwater Smartgrids to capture rainwater and open to the idea of sharing the data with the local water utilities.

The business model and economies of scale
Originally we thought it would be developing the technology that would be the challenge, however it was the business model that has created one of the greater barriers. The technology to successfully implement lot-level stormwater management is available, it is the change in the business model to get the technology installed that has been the difficulty, and part of that has been the unit cost. When you produce something for residential application, it has to be low cost because you are putting in thousands of them. Yet, as a private property you cannot start to price things properly when you need a low unit cost. There needs to be one utility or municipality to install 10,000 cisterns to that we can price them at a reasonable cost. To reach the 40% implementation rate you need for a community to have noticeable reductions in stormwater, a sound business model is required. This barrier drove us to using the Community Based Public Private Partnerships (CBPPP) business model. By involving water utilities and municipalities in the investment of the Stormwater SmartGrids we are now able to market the products at an affordable price due to economies of scale, and will be able to see much greater results with higher numbers of households participating in the stormwater capture.

At this stage, the impact in relation to water savings that RainGrid's Stormwater SmartGrids have had is at a very local scale, saving just over 200,000L of rainwater across two pilot cases. As more pilots are introduced, more savings will be possible. To implement more pilot projects, we need to have the initial support through a strengthened business model to ensure we can produce enough Stormwater SmartGrids at a low enough cost to reach the required implementation rate of 40%. Only then will we be able to see the true potential of this technology.

Engineering Firm Engagement
Probably one the most defining barriers to the rapid adoption of smart (AI/IoT) distributed stormwater management relates to the often risk adverse nature of municipalities and water utilities, leading to the continued investment in traditional stormwater infrastructure. This is understandable in one sense as it is part of their role to keep the community safe in regards to water management, however it can also lead to a stronger than necessary hesitation to adopt or trial new and innovative technologies that could support them in protecting their community and enhancing their current stormwater infrastructure and management.

4.1.3 Achievements and impacts
RainGrid has achieved international recognition for its transformative smart water technology and transformative utility business model. In 2015 RainGrid was designated by the Water Research Foundation (WRF) Leaders Innovation Forum for Technology (LIFT) as an Intelligent Water System for demonstration adoption and implementation by municipalities and utilities.

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RainGrid has also achieved recognition as a leading social enterprise when it was selected for the 2013 Impact 8 Social Innovation Generation Accelerator by the MaRS Discovery District, and through its successful win at the Toronto, 2014 Challenge Cup-Smart Cities business competition for the most promising, world-changing municipal startups. RainGrid also received a 2016 Best for the World designation as a B Corporation in environmental and best overall categories. This recognition has acted as an enabler in strengthening the interest in the project and in showcasing its potential to a wider audience.

5. Links to the SDGs

Table 5. Links to the Sustainable Development Goals

Sustainable Development Goals and Targets	
SDG 6: Clean water & sanitation **Ensure availability and sustainable management of water and sanitation for all**	
6.1	By 2030, achieve universal and equitable access to safe and affordable drinking water for all
6.3	By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally
6.4	By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity
6.5	By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate
6.6	By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes
6.A	By 2030, expand international cooperation and capacity-building support to developing countries in water- and sanitation-related activities and programmes, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies
6.B	Support and strengthen the participation of local communities in improving water and sanitation management
SDG 11: Sustainable cities and communities **Make cities and human settlements inclusive, safe, resilient and sustainable**	
11.5	By 2030, significantly reduce the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations
11.B	By 2020, substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change, resilience to disasters, and develop and implement, in line with the Sendai Framework for Disaster Risk Reduction 2015-2030, holistic disaster risk management at all levels
SDG 13: Climate Action **Take urgent action to combat climate change and its impacts**	
13.1	Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries
13.3	Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning

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AI/IoT rain harvesting creates decentralized stormwater utilities. Similar in form and substance to distributed energy utilities of solar or wind, these ***Stormwater Smartgrids*** seamlessly integrate residential and commercial private-properties into a network of smart, asset-managed distributed water infrastructure. In doing so, AI/IoT rain harvesting closes one of the major gaps in a city's ability to successfully address so many interconnected Sustainable Development Goals through

- Security of drinking water supply (via groundwater recharge) (SDG 6.1)
- Protecting ecosystem water quality by reducing pollutants in stormwater (SDG 6.3)
- Optimizing sanitary sewage infrastructure (SDG 6.3)
- Increasing water efficiency through household reuse (SDG 6.4)
- Restoring environmental flows damaged by urbanization (SDG 6.5 & 6.6)
- Implementing rain harvesting, recycling and reuse technologies (SDG 6.A)
- Supporting community-scale participation in water and sanitation management (SDG 6.B)
- Reducing the potential for urban flooding (SDG 11.5)
- Increasing climate variable flood and drought resilience (post loss recovery) (SDG 11.B)
- Reducing energy use through decentralisation (SDG 11.B)
- Increasing urban resilience to climate related flooding (13.1)
- Enabling community participants to be better informed about their local climate and rainfall data (13.3)

6. Lessons Learned

Throughout these pilot projects we have learned a range of key lessons. These include how to improve the AI/IoT technology to make it more robust, to build-in additional time to test and adjust the systems in the field and the importance of community social-marketing from the beginning of the project. The follow section outlines these findings in more detail in the hope that these lessons will assist similar start-ups to get started on the right foot when introducing their innovative smart technologies to the market.

6.1 Technical lessons learned from the field

2015 1.0 Oakville

The technical lessons we learned from the proof of concept pilot were that residential scale AI/IoT rain harvesting could be designed to optimize smaller scale cisterns as stormwater management. Our early UI/UX dashboards were rudimentary but effective at illustrating the data of cistern levels, microclimate and simple operational parameters. Locating the pressure transducer sensor in a T-configuration with the electrically actuated drain valve resulted in pressure fluctuations that the sensor read as inflow, thus skewing the data.

The social engagement lesson drawn from this pilot was also very useful. The homeowner for whom the system was installed was happy with the installation but disliked the PoE cabling and PoE injector and the obvious connection to her interior household modem, situated in a second floor bedroom/office. This negative feedback prompted a rethink of the design a decision that significantly set back the development of the project, yet will benefit the project in the long-term.

2016 2.0 Toronto

In an effort to provide a lower property owner engagement footprint, we significantly modified the design of this pilot. The bulk of the R&D funding for this pilot came from an NSERC Green Homes research grant secured by our R&D partner institution, George Brown College Mechanical Engineering Advanced Prototyping Lab. The community social marketing engagement, installation, communications and half the maintenance costs of the installed RainGrid 2.0 systems were to be covered by a grant secured from CEC-NAPECA. This grant was conditional on it being spent by an NGO partner; so we contracted with two local NGOs. Unfortunately, the main NGO partner managing the funding were unable to deliver the most important elements of the engagement and community social marketing, to the extent that no formally recorded engagement, communications or replicable processes were instituted. Unfortunately, this resulted in a very limited evaluation of the pilot. What RainGrid can deduce about this pilot is tied to our analysis of the prototype technology's utility. In response to the push back received to the simple, functional PoE design, the 2.0 system was a very ambitious design, custom built on a limited timeline that precluded field tested prior to installation.

One significant improvement to our 1.0 and 1.5 proof of concept versions was a significantly upgraded UI/UX data visualization and analytics platform, divided between a residential and an administrative dashboard, the latter of which provided significant peripherals monitoring and fault assessment.

6.2 Prototypes take time to develop, test and get right

During our research and development stage we were warned to expect all of our field installations installed in the first two to three prototypes to not work as expected. While we were hoping this would not be the case, unfortunately many things did not go to plan.

In the first pilot we had issues with the sensors being damaged in harsh winter conditions, and when our communications software were replaced it required modifications to translate the signal to work with the household modem. For example, to eliminate the flow pressure reduction reading of the Specialties U7139 pressure transducer sensor, we modified the V1 500L cisterns with a separate port. This had the effect of subjecting the sensor directly to the water column which, when conditions turned cold, exposed the sensors to freeze-thaw conditions that damaged most of them the very first winter. The PoE communications and power platforms were then replaced with Zigbee wireless to household internet, which required a Zigbee modified TPLink TL-MR2030 router to translate the signal to the household modem.

In the second prototype the 2.0 system shortcomings mostly derived from having a limited budget, which significantly reduced our options to test and upgrade the technology when issues arose. For example, when the Zigbee radio transmitter specifications of signal strength range had difficulty with building mass and heavy rainfall, we determined that the units needed external antenna however without additional resources and support we were unable to fund this upgrade.

In addition, due to unexpectedly low sun exposure throughout the year the otherwise very energy efficient NiCad DC/solar power package failed to generate an adequate charge for the 4 AA NiCad batteries. This meant the rechargeable batteries failed entirely in cold temps as solar panels were not receiving the three hours of sunlight required to recharge them.

In Prototype 3, the electrically actuated valves turned out not to be weather proof (not ideal for a rainwater cistern) and many seized thereafter draining the power packs and the entire system failing. Once seized even the manual override couldn't drain the cisterns. Lesson learned, electrically actuated valves must fail 'open' but achieving that state requires constant energy inputs we could not install at the time due to the low power design.

In addition to this, as the system was dependent on residential internet access, low internet signals of loss of internet connections resulted in loss of data. Therefore wireless internet connections must be introduced with high power signal that cannot be disconnected to the internet.

These examples show the importance of taking the time to research, develop, test, and adjust smart technologies when developing prototypes, and also of the importance of the financial support needed to enable this time for research and development. Despite our many setbacks, we have learned a lot throughout this process and are eager to keep designing and testing our technology until is it robust enough to test on a much larger scale.

6.3 Strong community engagement is worth the effort

Limited community engagement with the pilot participants led to some challenges as well, as while most of the participants stated that they liked the technology, many disconnected their system (either intentionally or accidentally when disconnecting their internet service), earlier than expected.

Not surprisingly, participants linked their receptivity to use their SmartGrid to their interest in efficient watering of their gardens, or an interest in the technology itself. Technology early adopters were the majority of the participants with those interested in protecting the environment next on the adopters list. Unfortunately the lack of a formal community engagement with the pilot users reduced the wider community receptivity and interest in adopting the technology.

Based on the community engagement we were able to undertake, we do know that constant engagement and follow-up was necessary to ensure the users understood how to use the technology, were checking their systems regularly and knew how to use the systems to their advantage.

6.4 External support from the beginning of the project is essential for successful implementation

With regard to local water utility and political decision-makers their support was quite mixed. Though the Water utility managers were not as interested in participating in the pilot, the Toronto Sustainability Office endorsed it. This lead to municipal support through the city councillor's, however this support led mostly to further engagement and recognition and not to financial support for the pilots.

Local city councillors and federal members of parliament supported the project's demonstration of direct citizen engagement in flood and drought awareness, infrastructure and clean-tech climate change adaptation. National members of parliament (MPs) were the most supportive

due to the positive signals the project disseminated about clean-technology, climate policy and public engagement.

The most significant lesson learned about engagement was not to be deterred by the reticence of first pilot adoption of the system.

7. Conclusion and Next Steps

7.1 Conclusion

The five-year evolution of the Stormwater Smartgrid technology and business model for residential properties illustrates how complex it will be to realize the flood and drought adaptation possibilities that distributed AI/IoT rain harvesting holds for households, water utilities and builders. While the AI/IoT technology will rapidly evolve, and an out of the box product will arrive in the market similar to irrigation controllers, there remains much work to make intelligent rain harvesting a green building standard for flood and drought infrastructure, a secure water supply and the standard bearer of community climate adaptation. Rooftop runoff needs to be seen as a resource rather than a drainage problem. This is the least acknowledged but definitive One Water utility infrastructure frontier, and it offers the best hope that water utilities, in developed and developing economies, have for making progress toward normalization of the sustainable development goals.

In North America, institutional reticence about utility-owned AI/IoT rain harvesting infrastructure on private property is slowly being addressed. Utilities uncertain about adopting a full scale utility-scale approach can use a 'hybrid market-based' approach by distributing smart controllers as an integral element of their existing rain harvesting rebate programs with centralized real-time date visualization and analytics control within the utility.

The degree that utilities utilize residential smart rain harvesting is partially based on how well they see the potential to build a comprehensive One Water utility. Few can ignore the 40-60% of gross impermeable area represented by residential and small commercial property rooftops but the litmus test is whether they *integrate* those properties or simply *serve* them.

To capture relatively clean rainwater where it falls is relatively low carbon, highly integrated and comparative low capital input oriented solution compared to post property runoff conveyance LID and certainly centralized stormwater storage facilities.

7.2 Next steps for RainGrid

In light of water utilities or a critical mass of households not yet being willing to adopt smart distributed rain harvesting, RainGrid will meanwhile pivot to focus on its visibility for residential property developpers and smart city designers. To do this we will focus our work on development of a commercialized out-of-the-box technology for retrofit applications on existing rain harvesting systems or full home and commercial rain harvesting systems. By reducing the costs for the product, this could enable greater uptake by households and improve results seen at a community level.

In a related development, RainGrid has been actively engaged with the Mississauga-based Credit Valley Conservation Authority, and the Region of Peel, to establish the parameters for what is termed the smartBlu Roof feasibility study. In response to the discovery that the rain water harvesting system that was installed at the City of Mississauga's newly built headquarters was sized solely for toilet flushing (providing no attenuation benefits for the subsequently released City of Mississaugua stormwtaer utility fee), RainGrid and other partners were engaged to determine the feasibility of developing a real-time automated blue roof to offset the inability of the CVC HQ building to meet stormwater retention goals required to offset the Stormwater Utility Fee.

Supported by a substantial grant from the Federation of Canadian Municipalities, Municipal Climate Innovation Program (FCM-MCIP), and endorsed by Peel Region as a water efficiency strategy deployment, this study seeks to advance the blue roof design and implementation process with AI/IoT automation. Similar work is underway in Amsterdam hosted by the WaterNet utility. The objective of each project is to demonstrate at-scale systems for commercial rooftop runoff reduction for reliable, measurable and effective reductions in peak stormwater flow, enhancement of potable water offsets, and a vital tool for urban climate adaptation and resilience.

In addition to this, we are currently in the process of our third pilot, the 2018 Collingwood Smart Stormwater Pilot Project, involving 10 homes. This pilot is a demonstration of the seasonal flood prevention possibilities of the RainGrid Stormwater Smartgrid, and the Safer Sump IoT sump pump. This FCM funded pilot has taken its lessons from the challenging 2.0 & 2.1 versions and returned to the reliability of a PoE power and communications platform. However, the pressure transducer sensor has been replaced by an ultrasonic sensor. Once again this R&D was generously supported by an NSERC funded research partnership with George Brown College as a three project enhancement of the original design.Based on the findings from this pilot, we are looking to gain support for larger pilots.

The potential future of RainGrid's Residential Stormwater Smartgrid is most likely to be found in water scarce regions such as California and Texas – to which RainGrid deployed in 2018 in an effort to secure at scale demonstration partnerships. Significantly it was determined, specifically in Southern California, that AI/IoT rain harvesting's greatest potential lay in its application as a groundwater recharge technology in support of indirect potable reuse projects for water security, and desalination efforts resulting from aquifer overdraft.

Appendix

Stormwater Smartgrid: A Defining Technology and Business Model Challenge for Water Utilities

RainGrid's ongoing research and development (R&D) into residential-scale Stormwater Smartgrid technology parallels a body of R&D into business models concerned with the financing, implementation and operation of utility-scale distributed water infrastructure; what is more frequently being referenced as Community-based Public-Private Partnerships (CBP3). What RainGrid Stormwater Smartgrids bring to this R&D into decentralized asset-managed rain harvesting is a focus on residential property infrastructure. In that regard, our research and development has been focused on using AI/IoT as a means to overcoming institutional reticence about owning, installing and operating networks of rain harvesting on residential private property.

While at RainGrid we believe distributed networks of residential AI/IoT rain harvesting will be one of the defining characteristics of sustainable water utilities, that is still a highly marginalized market niche. The AI/IoT rain harvesting market is rapidly gaining ground however in commercial building construction and retrofit that uses AI integrated sensors and IoT automated systems to reduce their carbon footprint by managing lighting, AC/heating, parking, bicycle sharing, and now blue/green roofs, rain harvesting and potentially water treatment. The potential for being self-reliant means being insulated to the risks inherent in under-capitalized, low operational investment scenarios associated with large centralized utilities increasingly unable to meet optimum service levels. Water utilities that embrace AI/IoT distributed infrastructure will avoid the challenge of stranded assets they are increasingly unable to maintain. The challenge of climate change and the evolving information management capacity represented by the simple ownership of a smartphone, represents a tectonic shift for water utilities.

The decision-making advantages that property-specific, microclimate data offer in terms of flood and drought resilience are unprecedented. In an industry that utilizes models due to the challenge surrounding the collection of data, the opportunity for utility planners and policy decision makers to gain functional outcomes (e.g. stormwater runoff source control and retention, potable water demand management offsetting) as well as microclimate, property-specific data on wet weather events and their impacts would be an ideal situation.

K-water (the Korean Water Resources Corporation)
is the governmental agency for comprehensive water resource development in the Republic of Korea, with a large pool of practical engineering expertise regarding water resources that has been championing Smart Water Management for the past decade.

IWRA (the International Water Resources Association)
are a non-profit, non-governmental, educational organisation established in 1971, providing a global knowledge based forum for bridging disciplines and geographies by connecting professionals, students, individuals, corporations and institutions concerned with the sustainable use of the world's water resources.

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