ROADMAP TO SCALABILITY

JULY 2023

Document Title	SIMPaCT Roadmap to Scalability	Reference #	SIMP2301-B002

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Approved by	Sebastian Pfautsch		August 2023

Amendments			
Date	Version	Author	Amendment Description

Citation

This report should be cited as:

Wilmot, K., Tovey, A., Phansalkar, A. (2023) *SIMPaCT Roadmap top Scalability.* Prepared for the NSW Department of Planning and Environment, Water

Acknowledgements

The SIMPaCT project team would like to thank the NSW Smart Places team for their deep commitment to the project and its vision.

The primary authors would like to thank the SIMPaCT Scalability Working Group and all the project team contributors and reviewers for their expertise, deliberation, and patience.

EXECUTIVE SUMMARY

Smart Irrigation Management for Parks and Cool Towns (SIMPaCT) is a scalable integrated solution that uses smart technology to automate and optimise active irrigation systems. The solution has been developed to deliver value for urban parks and green spaces in four key areas: it helps to mitigate urban heat; it improves water efficiency; it optimises green infrastructure management; and it helps to ensure a high level of public amenity. The SIMPaCT pilot project developed new insights into how public parks can be designed, managed, valued and experienced. A SIMPaCT demonstration system has been implemented and is now operational at Bicentennial Park at Sydney Olympic Park (SOP).

SIMPaCT is a truly smart irrigation management for parks and cool streets that has the capacity to 'learn' and adapt dynamically to its local environment to maintain the correct water balance regardless of how water demands are changing. It maximises the cooling capacity of green infrastructure, responding to local conditions and delivering optimised irrigation in response to changing weather, changing plant needs, and dynamic variations of microclimate over time.

This report contains the details of the Roadmap for scalability that was developed through a process of collaborative enquiry. It is a record of the background research that generates and informs the Roadmap and presents scenarios for future development and a pathway to get there.

The future of SIMPaCT

The SIMPaCT pilot project has successfully demonstrated the SIMPaCT digital twin as a proof of concept and a fully operationalised working solution for Sydney Olympic Park. Looking to the future, the vision is for the SIMPaCT solution to scale and mature, to deliver urban cooling, water efficiency, improved public amenity, and optimal green infrastructure management for places and communities across Sydney, NSW and beyond.

A key focus is to assist other government agencies and water utility providers in transitioning to smart irrigation management. To this end, the SIMPaCT pilot project developed an actionable *Roadmap,* for scaling the SIMPaCT solution to other locations and contexts.

The Roadmap was developed through combining insights from the pilot project with a process of collaborative enquiry that included:

- Reviewing broader end-user irrigation requirements in locations and contexts beyond Sydney Olympic Park, through an extensive series of interviews
- Researching the commercial landscape for smart irrigation and the emerging smart city context
- Investigating and advising on the hardening and maturation of the SIMPaCT system as a scalable replicable solution.
- Introducing SIMPaCT to other NSW water utility providers with a view to expansion of SIMPaCT across other parkland assets and in other contexts.

The Roadmap defined five possible scenarios for the future of SIMPaCT:

1. Replicate the SIMPaCT solution as a commercial package for stand-alone place-based installations
2. Creative commons
3. Licensing
4. Subscription model
5. Public good big data

Scenarios

1. Replicate the SIMPaCT solution as a commercial package for stand-alone place-based installations.

Under this scenario, the focus would be on the commercial maturation of the SIMPaCT solution developed at Bicentennial Park, which would be replicated to deliver equivalent smart irrigation services to new customers in new locations.

Further testing would be required to understand the degree of customisation that may be required for each new location, proposed as 'SIMPaCT 2.0' implementations. This testing will determine the duration of future involvement of the SIMPaCT research team before SIMPaCT can be offered on a commercial basis. SIMPaCT 2.0 is also required to test the cost for a new instance of the SIMPaCT digital twin, given the potential complexities inherent in assessing a new location, designing the installation scope and details, as well as the hosting and staffing implications. These costs will be incurred even if there is little customisation required for the central platform.

As this Blueprint describes, SIMPaCT is retrofitted onto a third-party irrigation management system. Our market scan found that these commercial irrigation control products are becoming increasingly smart, using cloud-based data analytics and responding dynamically to changing environmental conditions, with the incorporation of soil moisture data and weather forecasts. The SIMPaCT digital twin, with its advanced analytics models and machine learning capability, is more sophisticated than these commercial products. SIMPaCT also balances a focus on plant health and water efficiency with optimised urban cooling; a capacity that is not present within any commercial solutions. These factors currently provide SIMPaCT with a point of difference advantage. However, this advantage is narrowing with the rapid development of commercial IoT, sensing and data analytics technologies. Against a backdrop of climate change, worsening urban heat and increasing water scarcity, there is likely to be growing demand for smart climate-responsive irrigation solutions, and the commercial ability to meet that demand is growing. In short, SIMPaCT may soon find itself facing competition from the very systems that it needs to integrate with in order to function.

The simplicity of a ‘cut and paste’ model means it has the potential for widespread uptake and therefore widespread urban cooling. Its opportunities are in locations such as development precincts; multiple park groupings; prestigious buildings, homes or sites; golf courses; large outdoor sports facilities; defence grounds; or locations with highly valuable plants. Some of these place owners will value the extra functionality of SIMPaCT no matter the extra cost. However, if the functional difference between SIMPaCT and the underlying irrigation management system becomes too narrow, the cost of adding SIMPaCT may be too high for many to consider it.

Many of the possible future opportunities for SIMPaCT are for local government parks, gardens and sporting facilities. Even when the local government authority is also the local water authority (such as in regional NSW), or has suffered the effects of droughts, and therefore has a heightened sensitivity to water management issues, the cost constraints inherent in local government may preclude consideration of buying a SIMPaCT solution. Indeed, these same cost constraints currently preclude investment in more basic commercial irrigation systems by many local authorities.

The risk for this scenario is that SIMPaCT’s cost as a stand-alone product will be too high for most place owners, and that it will be competing with commercial systems that offer enough similar functions to outweigh any value. As such, it may only be viable for a few years until the market catches up and then only for a few less cost-sensitive user groups.

2. Creative commons

There is the potential to expand SIMPaCT’s reach and scope by making the solution open source under a creative commons license, allowing others to implement or grow it themselves. Standalone or grouped place-based installations are possible; or (depending on the nature of the creative commons license) commercial irrigation system providers may use SIMPaCT to improve their own product offerings. Other research teams may wish to build on the SIMPaCT solution under this scenario, which suggests the possibility of new functionality and applications.

3. Licensing

Use of the SIMPaCT solution could be licensed to a commercial irrigation system provider. Care would be needed in developing the licence conditions to ensure that the purpose of SIMPaCT is clearly defined and understood, and that it is marketed, installed and maintained in a way that does not detract from SIMPaCT’s reputation.

Licensing also provides a mechanism to broaden the geographic reach of SIMPaCT such as through working with universities or agencies interstate or internationally to implement it in their own region. In this case, implementation may take the approach of stand-alone or aggregated scenarios.

The main benefits of this approach are that it enables wider distribution without much direct involvement of the initial team, and that licencing fees may help to fund development work on SIMPaCT.

4. Subscription model

This scenario is for a district scale digital twin that offers SIMPaCT services on a subscription basis. The concept was devised in anticipation that the cost of a stand-alone SIMPaCT solution will be found to be too high for most place owners. The idea is to share the cost of buy-in to SIMPaCT by establishing a shared service that enables to access for smaller-scale landowners.

A technology provider would establish a single centralised digital twin, into which any standalone smart or semi-smart irrigation systems within the district may be integrated. This system would be developed to cater for scale, servicing multiple commercial systems, sites, and clients at once. The central SIMPaCT digital twin would perform modelling and forecasting and issue commands back to the multiple irrigation systems, optimising their operation.

Further work is required to determine the effort, time and cost that would be entailed in expanding the SIMPACT pilot platform for this application. Also relevant to its feasibility will be SIMPaCT 2.0 testing, on what inputs would be needed for each new location, and therefore the complexity of adding each new subscriber.

As well as facilitating a wider distribution and sharing of SIMPaCT's benefits, the data aggregation that this makes possible may allow coordinated management of water consumption across the region.

This scenario could be privately run on a commercial basis, possibly under a licencing arrangement, with similar risks to those from licencing to an irrigation system provider.

5. Public good

Taking scenario 4 further, an exciting possible future pathway for SIMPaCT is the establishment of a publicly owned and managed metropolitan-scale smart irrigation digital twin that delivers affordable and accessible services to place owners while also establishing powerful new water management capabilities for the water utility.

In the case of metropolitan Sydney, Sydney Water (or DPE Water) would establish a single central SIMPaCT digital twin. The benefit to irrigators is that a low-cost subscription model with an annual fee dramatically reduces the per-user cost. Connection could even be free, where the 'cost' to an irrigator is an agreement to hand a degree of autonomy over its irrigation systems to Sydney Water, in exchange for the benefits that SIMPaCT delivers.

In addition to the standard SIMPaCT functionality, two additional outcomes may be sought:

a. Catchment and regional-scale modelling that improves the optimisation of individual irrigation systems at the local scale

Large scale public data aggregation represents a new form of value creation that is not accessible to the commercial sector. Such big data has the potential to support catchment and regional-scale modelling of soil moisture relative to larger-scale weather and climate trends. If such modelling can be used to improve the performance of the SIMPaCT digital twin when operating at a catchment scale, it has the potential to improve the optimisation of individual irrigation systems at the local scale.

An additional benefit may be the ability to reduce the reliance upon on-the-ground IoT sensors. Where the SIMPaCT pilot project used 200 soil moisture devices, a future site of comparable size, connected to a metropolitan-scale model with big data modelling (and more advanced analytics capabilities), might operate effectively with many fewer sensors. Indeed, as such a system achieves scale it may be unnecessary for certain kinds of new site to have any sensors at all.

a. Utility-scale demand management for irrigation water

The primary benefit for Sydney Water of a metropolitan-scale SIMPaCT digital twin is the capacity for metropolitan-scale water management, and the management of peak water demand associated with irrigation. Potential cost savings could be enormous and, in theory, justify the significant initial investment required to develop and operate such a system.

A precedent for utility-scale peak demand management has already been set by energy utilities. Water peak demand management can be achieved because:

- Irrigation can be staggered across multiple sites prior to a heat event.
- Pre-watering of soil aids in the future infiltration of water and slow irrigation over a longer period may be more effective at maintaining optimal soil moisture than short-period deluge, so water demand can be spread over longer periods.
- Optimising water delivery across multiple sites avoids over-watering around peak irrigation events.

Management of peak demand helps in the following ways:

- Avoids expensive water supply that is used to service peak demand (e.g. desalination water, recycled water)
- The need for pre-pumping of water in reservoirs, to meet demand, can be more effectively managed, and potentially reduced. Together with not having to treat as much water during heat waves when energy costs are high, this may have enormous energy cost savings, as well as carbon emission savings.
- Given that pumping of water for irrigation contributes to peak energy demand on hot days (when air conditioning use is also high), there are potential outcomes for reducing energy peaks that benefit electricity utilities.

This vision has been developed in collaboration with Sydney Water, with the focus on metropolitan Sydney. However, the scenario could easily be applied to other locations and water utilities, tying in to state and federal government water management policies. SIMPaCT could be owned and managed by DPE Water, with coalitions of smaller local water authorities coordinating water management in their own regions.

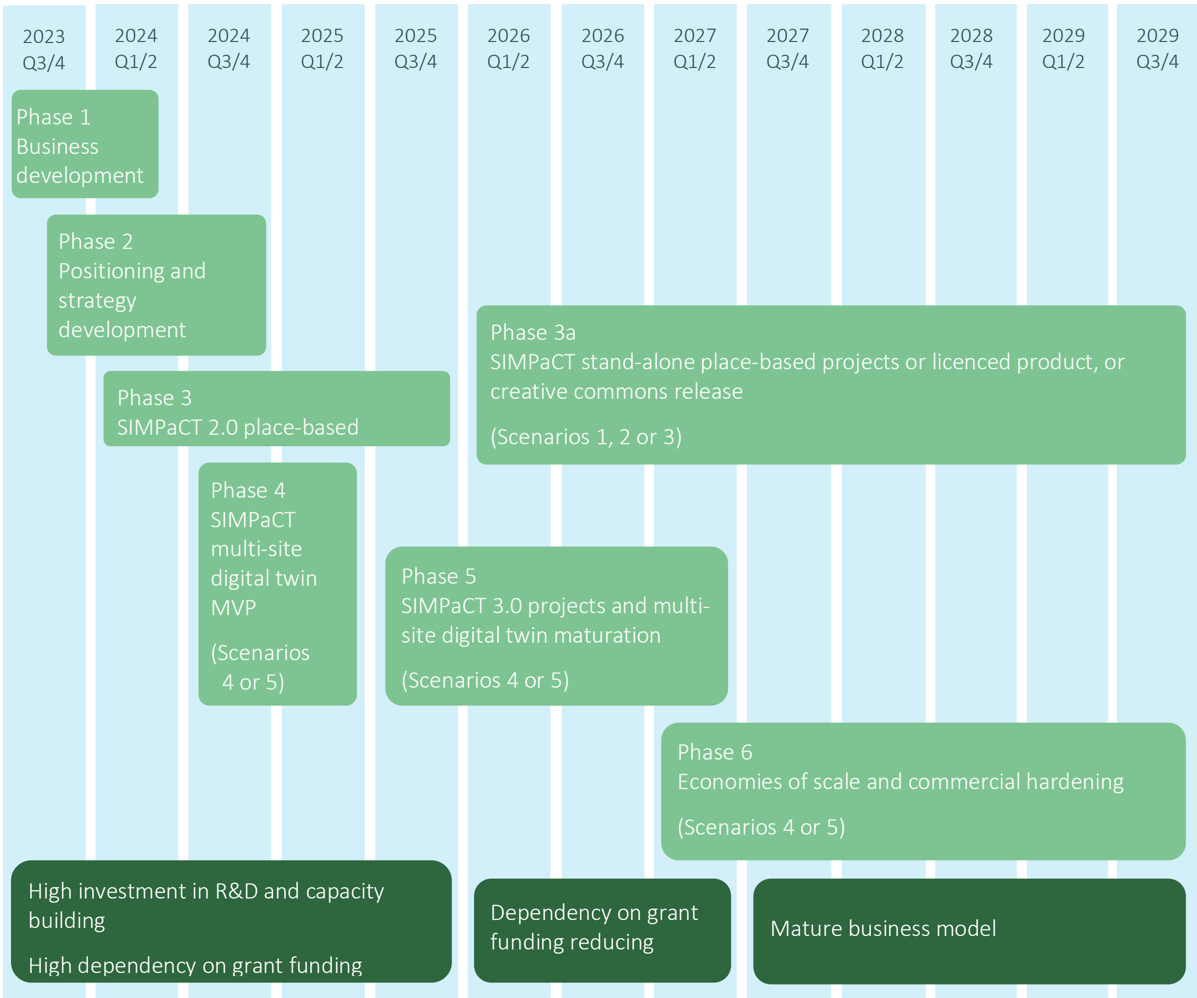
Scenario 5 is based around a core concept of big data aggregation, and the value that this can unlock. This is an emerging trend in IoT and smart cities that can be expected across multiple sectors in the coming years.

The pathway

The SIMPaCT Roadmap has defined six phases for scaling SIMPaCT. The implementation pathway accommodates making a start on all scenarios in the first three phases, deferring determination of one favoured scenario until further insights emerge from SIMPaCT 2.0 place-based project (Phase 3). These insights should relate to:

- The ease or difficulty of maturing the SIMPaCT solution in its current form
- The degree of additional development and customisation required to adapt the solution to new contexts
- The cost of delivery relative to various new contexts and key factors
- The business case for establishing and maintaining the solution in new contexts

Following phase 3, divergence may occur based upon insights and market conditions. It is possible that all scenarios continue to develop in parallel, or that certain ones emerge as more promising.



An overview of the six phases of the SIMPaCT scalability pathway

Phase 1 Business development

Leverage the initial success of the SIMPaCT pilot to flesh out new proposals and secure new support and funding.

Phase 2 Positioning and strategy development

Gather evidence, position key partners, confirm value propositions and further develop a longer-term strategy.

Phase 3 SIMPaCT 2.0 place-based projects

Secure new stand-alone place-based projects to test replication requirements with new place owners, new irrigation systems, and new contexts and challenges. These new projects will seek efficiencies in approach, design, methodology and costs.

Phase 3a SIMPaCT stand-alone place-based projects or licenced product, or creative commons release

Subject to the results of SIMPaCT 2.0 projects in Phase 3, SIMPaCT may be ready for a roll-out under one or any of Scenarios 1, 2 or 3. Phase 2 will inform which of these scenarios should proceed, and whether this would be the only future for SIMPaCT or if development towards scenarios 4 and 5 should occur in parallel.

Phase 4 SIMPaCT multi-site digital twin Minimum Viable Product

This progresses the metropolitan-scale data aggregation platform of scenarios 4 and 5. The Minimum Viable Product (MVP) is a proof of concept that will demonstrate SIMPaCT working as a single digital twin across multiple sites.

The MVP would initially be created as a standalone instantiation of the existing SIMPaCT digital twin that will operate in parallel with individual site instantiations of SIMPaCT to test and compare the system to address challenges of interoperability, data harmonisation and heterogenous data synthesis. This phase will also inform the viability and appropriateness of continuing with scenario 4.

Phase 5 SIMPaCT 3.0 projects and multi-site digital twin maturation

Secure new place-based projects that use only the Smart Irrigation Digital Twin from day one. Further testing of the model is required where site establishment is outsourced to the irrigator, to establish interoperability with diverse commercial providers, to develop advanced data analytics and demand management capabilities, and to harden the commercial model.

Phase 6 Economies of scale and commercial hardening

With the data from many sites connected across Sydney the optimisation benefits can be shown, measurable demand management benefits become apparent for Sydney Water, and an affordable subscription rate for SIMPaCT customers can be supported by economies of scale.

By Phase 6, SIMPaCT should be rapidly emerging as a ubiquitous central element in Sydney's irrigation landscape. It should also be garnering significant international attention and acclaim.

CONTENTS

ABBREVIATIONS

AI	Artificial intelligence
APIs	Application Programming Interface
BoM	Bureau of Meteorology
CfS	Committee for Sydney
CRC	Cooperative Research Centre
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CTS	CentraTech Services
DPE	NSW Department of Planning and Environment
ET	evapotranspiration
FM	Field Mouse
GCC	The Greater Cities Commission
GHG	green house gas
HARC	Hydrology and Risk Consulting
ICT	Information and Communication Technology
IoT	Internet of Things
IoTAA	IoT Alliance of Australia
IP	Intellectual property
iPART	Independent Pricing and Regulatory Tribunal
LGA	local government authority
LGNSW	Local Government NSW
LoRaWAN	Low Power Wide Area Network
MVP	Minimum Viable Product
NSSN	NSW Smart Sensing Network
OPENAIR	Operational Network of Air Quality Impact Resources
PCI	Park Cool Island
PET	Potential Evapotranspiration
ROI	Return on Investment
SCADA	Supervisory Control and Data Acquisition
SIMPaCT	Smart Irrigation Management for Parks and Cool Towns
SOP	Sydney Olympic Park
SOPA	Sydney Olympic Park Authority
The ARCS Group	The Australasian Railway Consultancy Services Group
TW	Total Water
UGI	Urban Green Infrastructure
UHI	Urban Heat Island
UNSW	University of New South Wales
UTS	University of Technology Sydney
WSU	Western Sydney University
WSUD	water sensitive urban design

GLOSSARY

Irrigation	The provision of water to plants in managed landscapes. *Active* irrigation involves the provision of water using physical infrastructure (e.g. pumps, pipes, valves and sprinklers).
Application Programming Interface (API)	An Application Programming Interface (API) is a way for two or more computer programs to communicate with each other. It is a type of software interface, offering a service to other pieces of software. In the SIMPaCT context, an API is used for the transfer of data between any two components of the data architecture, above the level of the communications networks.
Console	The irrigation system at Bicentennial Park is divided into five operational areas, each of which is connected to a console (numbered 81-85). Each console has a number of stations associated with it.
Data architecture	Data architecture describes an integrated system of platforms, services, databases, dashboards, communications technologies and physical hardware that comprise a complete end-to-end digital solution.
Data schema	Metadata and telemetry fields are generally characterised in a data schema that defines their intended applications, validated field entries, and data formats. Any smart sensing project like SIMPaCT should develop its own data schema.
Evapotranspiration	Evapotranspiration is the biophysical process where water is lost through the leaves of plants, cooling the air.
Location	A 2D geospatial point defined by a latitude and longitude, associated with the deployment of a specific sensing device. There may be one or more locations within a station and each location should be associated with a station number.
LoRaWAN	Long Range Wide Area Network (LoRaWAN) technology is a bi-directional radio communications technology that has been developed for connecting distributed Internet of Things devices within a local area. LoRaWAN is widely used for supporting smart low-cost sensing device networks of the kind used for SIMPaCT.
Metadata	Metadata is 'data about data', and is defined by 'fields', each of which describes a specific attribute of project data (or other aspects of a project). Each metadata field needs to serve a clear purpose that is tied to a data use case and the operation of a sensing device network. In the SIMPaCT context, metadata is critical for: installing, administering and operating a sensing device network; managing and formatting data; interpreting data; and sharing data. Metadata can be updated over time but tends to remain relatively fixed compared to telemetry.
Park Cool Island effect	The Park Cool Island effect describes how the evapotranspirative cooling effect of plants in a park can lower the air temperature in and around the park. See Appendix 3 for a more complete explanation.
Sensing Device	A complete device, sold as a commercial product to end users. A sensing device will typically consist of: a housing; a microprocessor; a sensor board; one or more sensors; a power supply; a communications module; data storage. A sensing device such as a weather station includes multiple sensors and multiple component parts that are mounted alongside each other.
Sensor	A specialist component designed to capture empirical data about a directly observed phenomenon. A sensor is a *component* within a device that is generally sold to device manufacturers. A sensor cannot function separately to a supporting device.

SIMPaCT digital twin	The SIMPaCT digital twin is an integrated package of hardware and software components, for data collection, data management, advanced analytics, dynamic feedback and smart irrigation control.
SIMPaCT solution	The SIMPaCT Solution is defined as a combination of: an existing irrigation system; the SIMPaCT digital twin; SIMPaCT dashboards; and a SIMPaCT methodology.
Solenoid	A piece of physical hardware consisting of an automated irrigation valve. One solenoid services one station, which is an operational area watered by one or more sprinklers.
Sprinkler	An end point in the irrigation system that distributes water to an area of ground surrounding it.
Station	A geospatial polygon that defines an area of ground as a distinct operational domain of the irrigation system. Each station is serviced by one solenoid, which controls the release of water through one or more sprinklers within the station. Station boundaries are defined by the reach of water spray from sprinklers within that station. Stations are an existing operational category used by Total Water and are tied to the fixed irrigation infrastructure.
Telemetry	Telemetry describes a measurable phenomenon that changes over time, expressed in a time series. It refers to all dynamic information reported by a sensing device, and includes sensor data (e.g. soil moisture or temperature) as well as device functionality variables (such as battery voltage and communications signal strength). Telemetry can also include data from third-party sources, such as meteorological data received from the Bureau of Meteorology. Telemetry values are dynamic and can change every time a device reports. They can be viewed as an archival data set, or as a near-real-time data stream.
Urban Heat Island effect	The Urban Heat Island Effect (UHI) is an effect found in urban centres, where the ambient air temperature is slightly higher than the surrounding area. The effect is caused by the thermal mass of the built environment radiating retained heat back into the air. UHI is often most pronounced late in the day, when retained heat from afternoon sun keeps urban temperatures elevated into the evening.

1 INTRODUCTION

1.1 SIMPaCT summary

Smart Irrigation Management for Parks and Cool Towns (SIMPaCT) is an action research project that uses smart technology to induce physical cooling of the environment inside and around urban parks and green spaces, optimise water usage, and to inform the activities of park irrigation operators and users. This addresses four key challenges facing urban parks: urban heat; water efficiency; green infrastructure management; and the maintenance of public amenity. The project opens new pathways for how public parks can be designed, managed and experienced. A pilot has been implemented and is now operational at Bicentennial Park at Sydney Olympic Park (SOP) with testing over the coming summer (2023/24) required to verify water savings and cooling effects. Sydney Olympic Park is a suburb of high-rise apartment living in Greater Western Sydney, located 13 kilometres west of the Sydney central business district, in the local government area of the City of Parramatta Council.

While irrigation systems that help reduce water usage are commercially available, for example those that skip one or more scheduled irrigation events when rain is forecast, none have the capacity to 'learn' and adapt dynamically to their local environment. This is especially limiting in a complex environment like urban parks and streets where vegetation type, species composition, water requirements, solar exposure and soil moisture vary widely. There is a need for a truly smart irrigation management for parks and cool streets that maximises the cooling capacity of green infrastructure, responding to local conditions and delivering optimised irrigation in response to changing weather, changing plant needs, and dynamic variations of microclimate over time. This ability to maintain the correct water balance regardless of how water demands are changing is the solution offered by SIMPaCT.

1.2 Purpose of this report

The SIMPaCT pilot project has successfully demonstrated the SIMPaCT digital twin as a proof of concept and a fully operationalised working solution for Sydney Olympic Park. Looking to the future, the vision is for the SIMPaCT solution to scale and mature, to deliver urban cooling, water efficiency, improved public amenity, and optimal green infrastructure management for places and communities across Sydney, NSW and beyond.

A key focus is to assist other government agencies and water utility providers in transitioning to smart irrigation management. To this end, the SIMPaCT pilot project developed an actionable Roadmap for scaling the SIMPaCT solution to other locations and contexts.

The Roadmap was developed through a process of collaborative enquiry that included:

- Reviewing broader end-user irrigation requirements in locations and contexts beyond Sydney Olympic Park, through an extensive series of interviews
- Researching the commercial landscape smart irrigation
- Investigating and advising on the hardening and maturation of the SIMPaCT digital twin as a scalable replicable solution.
- Introducing SIMPaCT to other NSW water utility providers with a view to expansion of SIMPaCT across other parkland assets and in other contexts.

This report contains the details of the resulting Roadmap and a record of the background research that generates and informs the Roadmap.

1.3 Structure of this report

The background research underpinning the conclusion of the scalability enquiry ranged very broadly, examining, for example, the problems SIMPaCT strives to address and how it does that, recommendations for scaling smart city solutions, opportunities and contexts for a future SIMPaCT, and the commercial market into which it will fit. This report presents the pieces of this jigsaw with each chapter dealing with one aspect. The report is structured as follows:

- Chapter 2: *Context and value proposition* – describes SIMPaCT and insights from the pilot project that would inform future instances, including cost implications and minimum possible scale. It notes the issues SIMPaCT aims to address, and summarises why SIMPaCT is needed and how it is solves the issues raised.
- Chapter 3: *Enquiry for scalability* – provides a review of the emerging smart city field, prerequisites for scaling such projects, and how SIMPaCT is different from what the commercial market currently offers. It examines the context of possible future users of SIMPaCT to understand motivations and barriers for future implementation.
- Chapter 4: *A high-level vision and strategy for the future* – examines how well SIMPaCT fits criteria for scaling, the opportunities and challenges the examination uncovers, and strategies to facilitate scaling.
- Chapter 5*: Scenarios for a future for SIMPaCT* – draws on the scaling strategies and background research to identify five scenarios for scaling SIMPaCT at different levels of commercialisation and targeting different possible users and scales. It explains a vision for a future large-scale SIMPaCT that offers a public good service.
- Chapter 6: *Scalability pathways* – describes the potential pathways to scaled, commercially robust versions SIMPaCT and details what activities are needed to achieve this.

- Chapter 7: *References* provides a reference list.
- Appendices are included where additional detail may be helpful to some readers:
    - Appendix A is a record of the consultations undertaken
    - Appendix B defines low-cost sensing devices
    - Appendix C details the costs involved in a project such as SIMPaCT
    - Appendix D details SIMPaCT attributes in the context of established quality criteria
    - Appendix E has a literature review and details on the SIMPaCT value proposition

2 CONTEXT AND VALUE PROPOSITION

2.1 Smart irrigation

Water scarcity is a persistent and growing global and Australian issue. Especially, irrigation for agricultural production consumes very high volumes of water (e.g. 7.8 million megalitres of water in 2020-21 in Australia) (Australian Bureau of Statistics, 2022). This has resulted in the rising demand for new irrigation systems, such as sub-surface drip or capillary systems and smart detection devices (e.g. irrigation system controllers) to enhance the overall water efficiency of irrigation systems (Verified Market Research, 2022).

Development of smart irrigation technology has been fast paced, especially for crop and dairy farmers in Australia, involving sensors and satellites which allow irrigators to control the automated watering system remotely (Jeffery & Becker, 2021). Use of irrigation system controllers is becoming common for residential irrigation. These controllers range from very basic entry-level to more sophisticated units with remote control via Wi-fi from mobile phone apps and compatible with weather sensors (e.g. Hunter Irrigation Controllers for residential use). Optimal scheduling linking with the Bureau of Meteorology's 7 day weather forecast is becoming common for irrigation in parks and open space in Australia (Aquamonix, 2022).

Smart irrigation is at the end of a continuum of increasing technology sophistication and functionality that starts with the manual irrigation systems of the past:

1. Passive irrigation (e.g., certain water sensitive urban design (WSUD) approaches direct stormwater to street trees)
2. Active manual irrigation (hand application using hose/can; water trucks visiting street trees)
3. Plumbed/active irrigation
    a) Active with manual control – where a person needs to physically turn on/off taps/valves)
    b) Active semi-automated – where valves/solenoids have self-contained timers, which may be digital or mechanical, that are set and forget. No wireless data connections. Operator must physically visit and adjust settings for each piece of hardware.
    c) Active with centralised site-based control system – includes classic Supervisory Control and Data Acquisition (SCADA) systems and various other more modern systems (based on our interviews with Councils, this is probably the most common type of existing irrigation system)
    d) Active with centralised cloud-based control system and basic smarts – includes systems like Fieldmouse (FM) and most advanced commercial systems. Allow access to the control system via any connected device. Smarts may include more advanced scheduling, alerts, and weather response.
    e) Advanced smart irrigation – SIMPaCT. Machine learning is combined with the multi-factor real time hydrological modelling and data from on-site sensors for predictive controls that optimise between the different constraints of water efficiency and healthy plants. The system is able to learn from its experience and improve during ongoing operations.

The three sectors where smart irrigation is evident are residential (consumer products), smart cities and places, and agriculture. While SIMPaCT may ultimately be applicable in residential and agricultural contexts, the focus of the SIMPaCT pilot was on smart cities, at a scale of precincts or larger. Future opportunities were tested in this research, refer Chapter 3.

2.2 Designing impactful smart city projects

Successful smart city projects are about more than technology. They combine a human-centred design approach with consideration of place, governance, operations and evolving technologies in a holistic system. The resulting design and deployment of smart-city strategies and systems prioritises social and environmental impacts while also improving the efficiency of resource use and infrastructure management.

The framework diagram in Figure 1 illustrates this system. The central goal is to achieve social and environmental impact, defined in the box to the right as outcomes related to health and wellbeing, liveability, environmental protection, resource efficiency, climate resilience, collaboration, equality and inclusion. Activities to reach this goal are categorised under six domains of being people-centric, partnering, technology, design and governance, data, and organisational capacity. Successful projects are seen to address all of these domains.

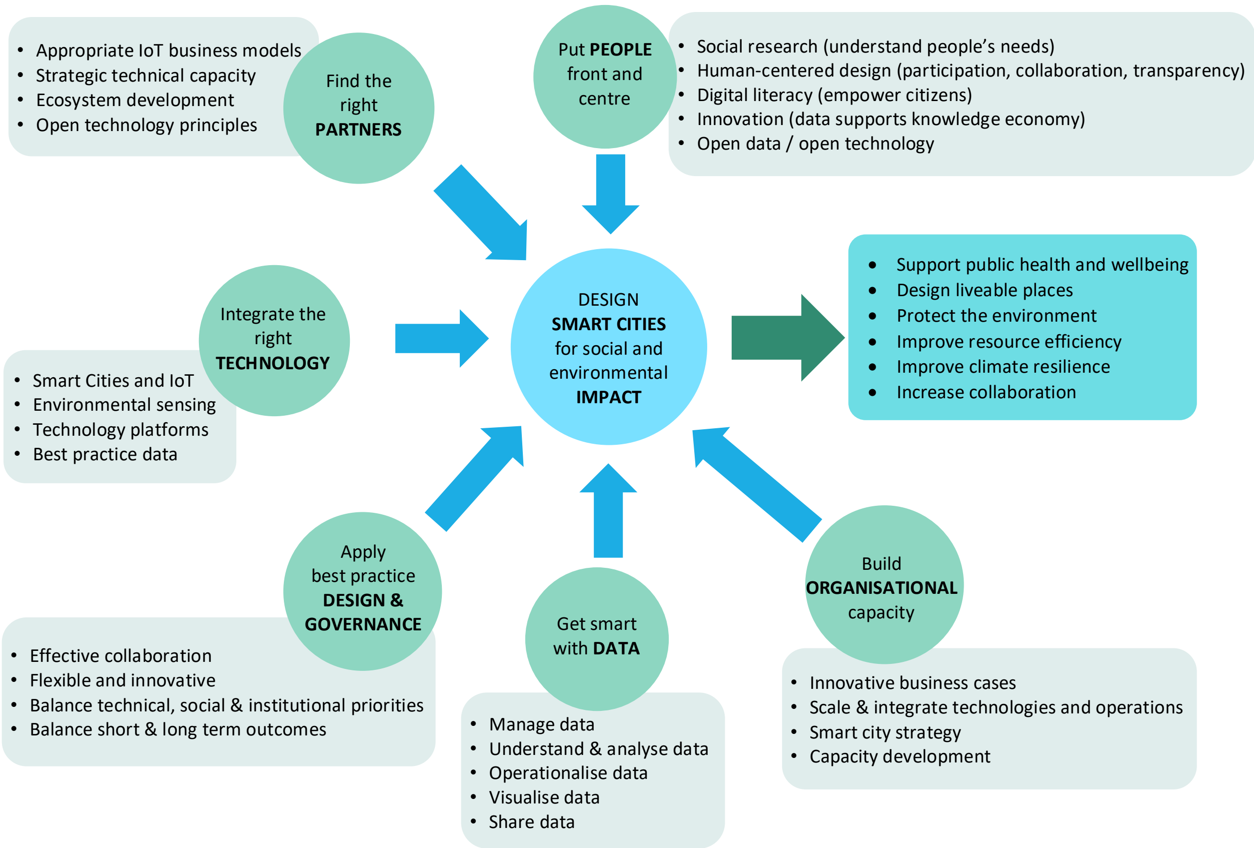


Figure 1 Framework for a smart city project. The various elements of a project are shown around the primary goal of impact, defined by a range resultant outcomes. Source: Institute for Sustainable Futures, UTS.

The SIMPaCT solution uses this approach. It seeks to make a transformative change to the park management ecosystem in collaboration with the park managers, the right mix of industry expertise and government, and with regard to the outcomes for the local community. Commencing with identifying the unique challenges of the location it targets a data-driven solution to create positive impact.

Guided by this view, to replicate SIMPaCT in the future will require consideration of the particular settings for each new instance. As well as the primary goal of the new instance and the physical location attributes, the impact on the local community, organisational capacity, and project partners will influence the installation. To what extent adjustments will be needed to the SIMPaCT solution and whether default settings will be sufficient will need to be tested in a new round of trial projects.

2.3 Smart Low-cost Sensing Devices

Smart - 'Smart devices' are devices that are connected to the Internet of Things (IoT). They communicate data wirelessly, in near real-time, enabling large distributed networks, and the utilisation of live data streams. More sophisticated smart devices may have varying levels of onboard processing for data correction and abstraction, as well as smart operational functionality.

Low-cost - The term 'low-cost' is broadly used within the IoT and smart cities sector, as well as by state and international organisations concerned with meteorological and air quality monitoring, to describe smart devices that are low in cost compared to more established types of (generally) higher performance equipment that is used to measure the same variables.

Discussion of the key challenges and the value proposition of smart low-cost devices is provided in Appendix B.

2.4 An introduction to the SIMPaCT pilot project

2.4.1 Overview

Led by Western Sydney University and co-designed with several partner organisation from government, tertiary education and private industry, the SIMPaCT pilot project ran between November 2021 and July 2023. It saw the establishment of SIMPaCT as a demonstrable solution to four key challenges facing the resilience of Bicentennial Park: urban heat; water efficiency; urban green infrastructure (UGI) management; and the maintenance of public amenity

The SIMPaCT pilot project uses smart technology to induce physical cooling of the environment in Bicentennial Park, optimise water usage, and inform the activities of park irrigation operators and users. It takes an approach that optimises soil moisture conditions to maximise the delivery of coolth inside and downwind of the park. A digital twin of the site uses a combination of geo-spatial modelling and machine learning to optimise irrigation management for the best soil moisture conditions for different vegetation types under a wide range of weather conditions. The goal is for the plants in the park to operate at their maximal rates of transpiration, which in turn results in the highest degree of air cooling. The advanced analytics capability of SIMPaCT includes a decision-making module that selects whether to prioritise cooling or water efficiency based on data about current conditions and predictive modelling.

Data for current conditions come from sensors situated across the park that continuously measure soil moisture, air temperature, wind speed and rainfall. Forecasts from the Bureau of Meteorology are used for predicted weather patterns. Based on these data, the digital twin simulates cause and effect until an optimal soil moisture status is consistently achieved, after which the AI module takes over the management of the irrigation system in Bicentennial Park itself.

SOPA staff can view conditions on an operational online dashboard and SIMPaCT issues them daily status reports. SIMPaCT also live streams environmental data to a public online dashboard to support decision making by park users about when and where to spend time in the park.

The aim of the pilot was to design and implement a fully operational demonstration of the SIMPaCT solution, capable of delivering ongoing long-term value to SOPA. It serves as the start of a scalable expansion of the SIMPaCT solution. The project opens new pathways for how public parks can be designed, managed and experienced.

Key deliverables of the SIMPaCT pilot project can be divided into:

- **Asset delivery** - the delivery of the SIMPaCT solution as a replicable and scalable digital twin and associated methodology: establishment of the device network in Bicentennial Park, design and instantiation of the predictive models, irrigation adapter, data management platform and integrated digital architecture; creation of the methodology, strategy, schema and operational model regarding data collection and the functions and settings of the control system.
- **Activity delivery** - the demonstration of SIMPaCT in an operational context within Bicentennial Park, plus supporting documentation: flow of live sensor data, ingestion of weather data, data storage and management, model training, control of the existing system; operationalise and handover to SOPA; document the project.

2.4.2 Funding

SIMPaCT was funded through the Smart Places Acceleration Program under the Digital Restart Fund, administered by the Department of Customer Services of the NSW Government. SOPA was awarded $2.5M to finance SIMPaCT. The project was co-funded by SOPA and Sydney Water, with in-kind contributions from most of the other partners, towards the establishment of environmental sensor networks and a SIMPaCT digital twin.

2.4.3 Partners

Partners for the SIMPaCT pilot project represented the core roles of a place owner; project design, management and delivery partner(s); an irrigation manager; IoT providers; and irrigation model developer/provider. The project also has a strategic advisor and principal sponsor.

The project was led by Western Sydney University (School of Social Sciences), and was delivered in partnership with the following organisations:

Project lead	Western Sydney University (WSU)
Place owner	Sydney Olympic Park Authority (SOPA)
Project design, management and delivery partners	WSU and University of Technology Sydney (UTS)
Internet of Things (IoT) providers	The ARCS Group and Eratos
Irrigation model developers/providers	Hydrology and Risk Consulting (HARC), Monash University, and WSU
IoT Technical Integration Manager	SAPHI
Irrigation manager	Centratech Systems (CTS)
Strategic advisor	Sydney Water
Lead government agency and principal sponsor	NSW Department of Planning and Environment (DPE) Water

In addition, the irrigation contractor, Total Water (TW) worked closely with the researchers throughout the pilot, contributing to the practical outcome.

2.5 The SIMPaCT value proposition

SIMPaCT was designed to address the challenges of irrigation at Bicentennial Park. These challenges exist within a broader context of growing environmental pressures that affect the whole of Greater Sydney, as well as other cities, towns and regional areas across Australia.

The SIMPaCT pilot project at Bicentennial Park was built around four key value propositions that impact the resilience of Bicentennial Park and its users:

Mitigating urban heat

The optimisation of irrigation to support maximum potential cooling from green infrastructure.

Managing green infrastructure

Well maintained and thriving green infrastructure assets, combined with operational efficiencies

Improving water efficiency

Irrigation control informed by data and predictive modelling, that optimises irrigation delivery, avoiding waste while ensuring plant health and cooling outcomes.

Maintaining public amenity

Maintaining cool, green places for public health and wellbeing through drought conditions

A literature review of the challenges and solutions, and details on how SIMPaCT makes a valuable contribution to the solutions, is provided in Appendix E. This is summarised as follows:

2.5.1 Mitigating urban heat

The Urban Heat Island (UHI) effect is that average temperatures can be higher in large cities than average rural temperatures, and Western Sydney suburbs in particular are facing serious UHI challenges. Increased urban heat is expected to have a direct negative impact on the health and wellbeing of people.

Irrigated urban parks and green spaces that provide evapotranspiration and shade are one of the most important defences we have against rising temperatures in our cities.

By modelling the water requirements for an area in detail, SIMPaCT can maximise the Park Cool Island (PCI) Effect, (a counter to the Urban Heat Island), by delivering precisely enough water for optimal plant health and maximum potential evapotranspiration across all areas of the park, relative to current and forecast environmental conditions. Designing a system capable of delivering a measurable increase in cooling was a primary aim for the SIMPaCT pilot project.

2.5.2 Improving water efficiency

Climate change impacts, urbanisation, and growing populations create competition for water, increase water quality issues and issues around water security and affordability. Sydney Water is faced by a confluence of challenges associated with peak water demands during heat periods, a warming climate, and a growing Western Sydney region. Extended drought has been identified as a contributor to UHI, leading to the need for increasing irrigation of urban green spaces to reduce the thermal stress of urban population and mortality of urban fauna and flora.

Historically during periods of drought-induced water stress, restricting outdoor water use has presented the greatest, lowest cost way to rapidly reduce water demand. The efficient use of water for irrigation is critical during periods of water scarcity to ensure that available water is used to support the greatest possible positive impact including the ability of a park to create a significant cooling effect during hot weather.

By responding to the actual water requirements at a detailed level, made possible through the accurate modelling of soil moisture combined with a seven-day weather forecast that prevents unnecessary irrigation ahead of rain events, SIMPaCT directly improves the water efficiency of an irrigation system. It enables the landowner to efficiently and effectively manage irrigation water demands and reduce precinct water consumption.

2.5.3 Managing green infrastructure

Challenges with the management of active irrigation are that poor management can result in damage to or loss of plants and the value they provide; it can equate to poor water efficiency, over-watering and undetected faults; and operational costs of green infrastructure management can be substantial, particularly where irrigation systems have manual input and labour costs are high.

SIMPaCT can improve the management of large green infrastructure assets through the use of live data and the optimisation and automation of an existing irrigation system. It captures real-time data about soil moisture that can be used to check the current functioning of the irrigation system; it can ensure that all areas of the precinct are irrigated optimally; and increased automation of the irrigation system can potentially reduce labour demand freeing up contractors to spend more time on tasks that they previously had little time for.

2.5.4 Maintaining public amenity

High-quality urban green infrastructure is a major contributor to public amenity, and with increased urban density public parks become more necessary for recreation, connection to the natural environment, and respite for physical and mental health, and community wellbeing. It is responsible and timely to develop optimised irrigation strategies that help reduce water use while still maintaining healthy green infrastructure, maintaining public amenity and supporting climate resilience.

In order to maintain high-quality green infrastructure and ensure that it delivers ongoing public amenity, many local governments across NSW need to use active irrigation systems. Thus, it is responsible and timely for NSW to develop optimised irrigation strategies that help reduce water use while still maintaining healthy green infrastructure, maintaining public amenity and supporting climate resilience.

SIMPaCT can directly improve the maintenance of public amenity in parks through the optimisation of green infrastructure management at a detailed level. As well as ensuring the efficient use of limited water for this purpose, it also supports a social license to maintain green infrastructure assets during droughts, when efficiency is a prerequisite for being permitted to irrigate.

2.6 The SIMPaCT Solution

2.6.1 Defining the current SIMPaCT solution

The SIMPaCT Solution is defined as a combination of:

- **An existing irrigation system:** the SIMPaCT solution is retrofitted onto and integrated with an existing irrigation system, which consists of fixed irrigation infrastructure (pumps, pipes, consoles, solenoids and sprinklers), and an irrigation management platform.
- **SIMPaCT digital twin**: an integrated package of hardware and software components, for data collection, data management, advanced analytics, dynamic feedback and smart irrigation control.
- **SIMPaCT dashboards:** public and operational dashboards for viewing and dynamically interacting with live data feeds from the SIMPaCT Digital Twin.
- **SIMPaCT methodology**: a set of approaches to the provision of data, the management of data (data schema), and the integration of the SIMPaCT digital twin with operational workflows.

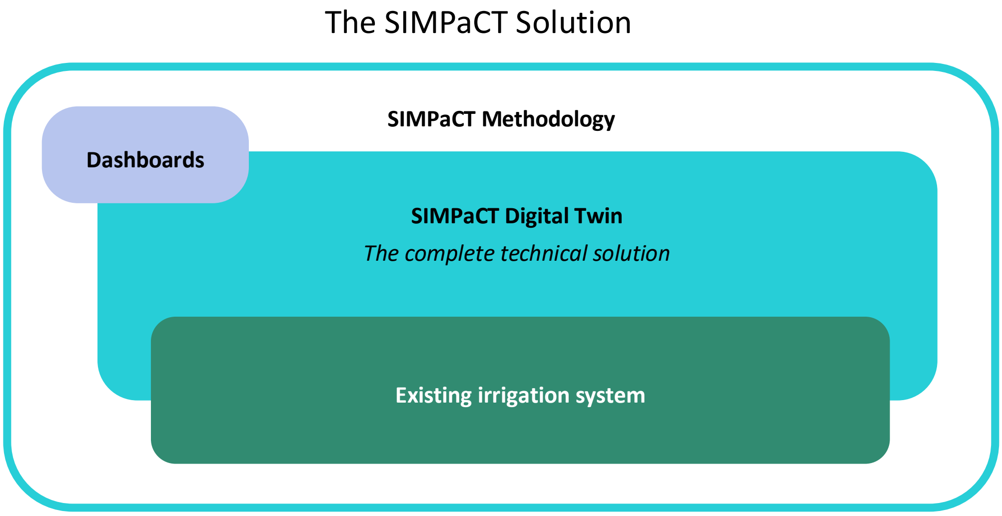


Figure 2. An overview diagram of the SIMPaCT Solution

For a more in-depth description of all elements of the SIMPaCT Solution, including technical details, please refer to the companion document *The SIMPaCT Blueprint*.

2.6.2 The digital twin data architecture

The SIMPaCT digital twin is built around a modular data architecture that connects multiple platforms, data models and digital services with an existing irrigation system, forming a single integrated functional system of data flows, analytics, control, and feedback.

The modular approach supports technical and commercial flexibility and scalability, as it means that various components of the architecture may be swapped out for alternative options that provide similar or expanded functionality.

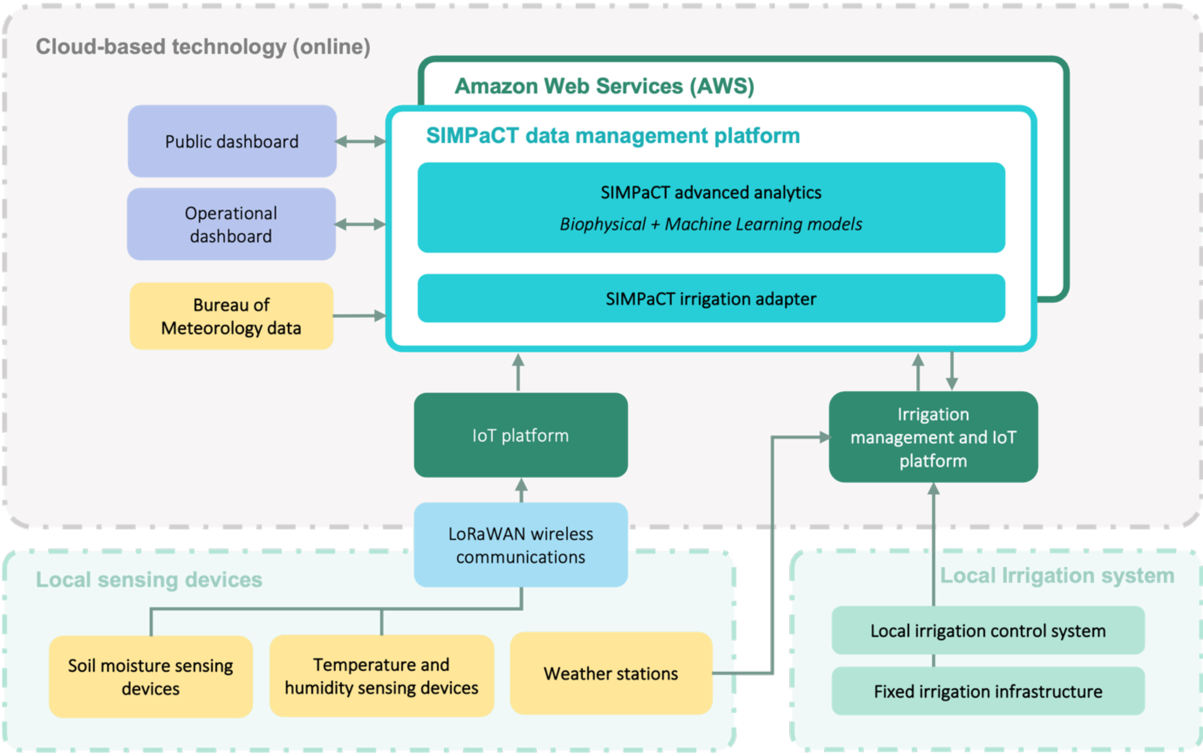


Figure 3. SIMPaCT data architecture

2.6.3 Critical assessment of the SIMPaCT digital twin

The ability of the SIMPaCT digital twin to mature into a scaled and hardened solution can be assessed according to established quality criteria that are widely recognised within the ICT sector. The five criteria addressed in Table 1 are of particular note for SIMPaCT. See Appendix D for a full list of definitions and critical assessments.

Table 1. An assessment of the SIMPaCT digital twin using standardised quality criteria

Definition	Relevance to the future of SIMPaCT	Comment
Interoperability *The ability of a platform or service to exchange data and integrate functionality via common shared language and protocols, usually defined by official standards.*	Interoperability matters for the future flexibility of SIMPaCT and our ability to easily and cost-effectively adapt it to function in new contexts.	Senaps aligns with best practice interoperability standards, supporting integration of multiple data streams and associated platforms and services, while minimising unnecessary custom development. APIs from the two IoT platforms and irrigation management system also align with best practice ‘restful’ interoperability principles. Future versions of the SIMPaCT digital twin would favour integrations with platforms that comply strongly with interoperability standards. The application of SIMPaCT to new contexts will undoubtedly involve new integrations. High interoperability will keep options as open as possible and ensure that future integrations can be achieved as cost-effectively as possible.
Hosting *The ability of a platform or service to provide an environment that is able to host a diversity of*	Hosting matters for the support of new functional capabilities required for maturing	Senaps is capable of hosting custom software such as the advanced analytics models used for soil moisture prediction and irrigation scheduling. These models can easily be managed and developed within Senaps.

Definition	Relevance to the future of SIMPaCT	Comment
sensing devices or discreet software modules.	SIMPaCT and meeting future end user requirements.	If new models or software modules need developing and integrating into existing workflows for future versions of SIMPaCT, Senaps is capable of hosting them.
Supportability *Relates to how well a platform or service can be configured and adapted to fit with the broader context of an organisation, and with the more specific context of a project or data use case.*	Supportability matters for the replication of SIMPaCT in new places, with new clients.	Senaps is highly *configurable* and *adaptable* for a variety of different contexts. For example, it can accommodate major changes to the structure of incoming data streams, meaning that future versions of the digital twin can work with different types of sensing devices and different IoT platforms. This ensures flexibility to refine the technical approach and business model.
Scalability *Refers to the capacity of a platform or service to expand or contract its functional capacity to meet changing needs.*	Scalability matters if much larger instantiations of SIMPaCT are to be considered in future.	Senaps is capable of handling huge volumes of data, many orders of magnitude higher than what is currently handled for the SIMPaCT 1.0 pilot. This means that the SIMPaCT digital twin has the potential to scale into a larger multi-site digital twin that serves many users (e.g. via a subscription model).
Reliability *Refers to the ability of a platform or service to do its job effectively across a defined period. An unreliable system is one that is unable to fulfill the functions expected of it.* *For SIMPaCT, this function is the delivery of continuous fit-for-purpose irrigation scheduling. A system may be operational but delivering a poor quality of service, and thus be 'unreliable'.*	Reliability matters to the commercial competitiveness of SIMPaCT and its success as a valued and trusted investment.	The reliability of Senaps is heavily contingent upon the availability of soil moisture sensor data. Sensing devices regularly display intermittent connectivity and go offline for a variety of reasons relating to the inherent limitations of the technology, combined with the complexity of the deployment context. If insufficient data is available for an operational station for several days in a row, the optimisation of irrigation scheduling will reduce to the point of unreliability. The SIMPACT pilot is not able to infer soil moisture telemetry for offline devices using data from other devices in the network, meaning that the reliability of the system (its ability to do its job) is heavily compromised by the reliability of devices and their communications. This indicates a major focus for future research and development of the system (see below).

2.6.3.1 Looking ahead: improving future reliability

Table 1 highlights the challenges of working with low-cost sensing devices as a key concern for the reliability of the SIMPaCT digital twin (see comment on 'Reliability'). Smart low-cost soil moisture sensors (refer Section 2.3 for definition) are a class of device that are the only practical and financially accessible hardware option for large-scale network deployments that have wireless data connection, low power demand and no above-ground profile. Unfortunately, low-cost devices also come with an inherent challenge of reliability, which is compounded by complex deployment contexts such as that experienced at Bicentennial Park. The challenge, which is recognised widely across the entire smart cities and IoT sector, is how to realise the significant benefits and opportunities of low-cost sensing, while addressing the practical challenges. The SIMPaCT pilot project made significant progress here (in ways that may contribute to the wider community of practice), however work is still needed to improve the reliability of SIMPaCT in the future.

Ideas that should significantly address the reliability issue outlined above were raised and actively investigated by the pilot project technical working group. They involved modelling missing data through a combination of spatial interpolation, cross-verification and machine-learning applications that couple similar telemetry and metadata profiles. This would entail the development of new custom models that are hosted within Senaps and inserted into the data flow upstream of the advanced analytics models. A different communications protocol (NBIoT) may also offer an alternative way forward (see

Appendix C, for further discussion). These solutions were ultimately parked as being out of scope for the pilot project, however they are likely to form a focus for continued research and development if future versions of SIMPaCT are established.

2.7 Pilot project lessons for scaling

Critical reflections from early versions of a new experimental approach inform improvements to future iterations, which should make each subsequent version easier. This section draws upon the experience of delivering the SIMPaCT pilot project, and critical reflections from the team (see *The SIMPaCT Blueprint*), to derive insights that are relevant to the scalability and future success of SIMPaCT.

2.7.1 Methodology

The first pilot indicates the range and depth of effort required for a successful outcome.

A well-designed governance model and defined role responsibilities are a critical foundation for effective collaboration and project success where the project requirements are complex and demand a broad range of specialist knowledge and skills.

Co-development with the end user (landowner and/or irrigation provider) is essential for the development a fit for purpose solution and building trust in the product.

Characteristics of the site location, particularly topography, soil types, and planting density, affect the deployment and operation of sensing devices. The lesson for future deployments is that site specifics need to be taken into account, and design and set up can add time to project establishment.

Procurement, deployment and troubleshooting of the technologies used, and in particular the sensing devices, takes a lot more time than expected. Since future SIMPaCT projects should determine the devices and deployment arrangements to suit each new case, they will not be a direct copy of the pilot project. Therefore, building in time at the project outset for iterative product and methodology testing and refinement would help to offset some of the deployment challenges; the 18-month duration of many funding arrangements is limiting in this respect.

2.7.2 Measurable benefits: estimating current and future return on investment

To inform the decision to invest in SIMPaCT, knowledge of the returns or benefits, how they will be measured, and whether they relate to the scale of a SIMPaCT implementation, (e.g. land size, number of devices), will be needed. This section explores the measurable benefits of SIMPaCT and whether they correlate with scale to determine if there is an unavoidable minimum scale for a future viable business model for SIMPaCT.

The benefits are presented in Table 2 according to a triple bottom line of economic, social and environmental outcomes, which aligns with the four value propositions of SIMPaCT.

Table 2. Measurable benefits of SIMPaCT

Benefit type	Examples	Relationship with scale	Measurability
Economic benefits	Reduction in water use, leading to reduced expenditure Reduced loss of plants due to mismanagement translates into reduced management costs for greenspace (e.g. no plant replacement costs) Improved amenity/aesthetic presentation reduces the risk of financial losses related to an inability to hire outdoor venues Energy demand reduction Improved outcomes from irrigation management, either as efficiencies or expanded tasks; costs savings possible in future irrigation contracts due to efficiencies.	These benefits are expected to correlate closely with scale. Water savings or reduced management costs of green space can apply to a small pocket park or garden, or to a large parkland. Energy demand reduction is a benefit for water utilities and can only apply at large scales as part of a potential metro-scale smart irrigation management solution, and are not accessible to individual landowners. If such scale could be achieved, the potential cost savings for a water utility could be substantial. There does not appear to be an upper scale ceiling to economic benefits.	Economic benefits can be measured by a landowner or other stakeholders (e.g. a water utility). Water use is already tied to a dollar value Plant loss and replacement rates over a given period can be expressed in monetary terms and compared to past periods. Financial impact of amenity/aesthetic presentation on income from hire is harder to quantify due to complicating factors (e.g. consider the impacts of Covid 19 on bookings) Energy use by utilities is already tied to a dollar value

Benefit type	Examples	Relationship with scale	Measurability
Social benefits	Improved public amenity, particularly during hot dry periods Improved urban cooling during heat events See (NSW DPIE, 2022c) for further guidance	Amenity scales quite closely with the size of a park or greenspace, and larger parks may be more resilient to harsher conditions. There is an optimal size for parks for urban cooling due to Park Cool Island Effect although the benefit plateaus at larger scales.	Indicators for this may include the number of people using the park; temperatures in the park; bookings for use of the park.
Environmental benefits	Healthier plants and habitats Potential biodiversity benefits Potential contribution to urban 'green corridors' Potential contribution to carbon sequestration capability of irrigated land	Larger scales are related to higher value for biodiversity, habitat and green corridors.	Indicators may include the number of different plant and wildlife species present; and measures of plant health.

2.7.3 Total cost of ownership

The total cost of ownership for SIMPaCT includes establishment costs (including capital expenditure on hardware, and the various costs of labour and services), and operating costs (recurring license and service fees, labour, etc.). For a new stand-alone place-based SIMPaCT solution, some of these costs are fixed, no matter what the scale of the project is, and others vary according to the specifics of the project.

A minimum threshold for total cost of ownership is a minimum amount that would need to be spent on any standalone instance of SIMPaCT, regardless of its size. The concept of minimum cost is important to determine the smallest viable size for a future SIMPaCT project. Even though benefits can be realised at the smallest scales, a cost-benefit imbalance may make investment undesirable.

The minimum cost estimate calculated for this report is unlikely to be achieved in practice. Each line item has an associated effort and value that is conservatively low, in order to demonstrate a theoretical minimum lowest cost for project establishment. The conditions and size of any future real world project are extremely unlikely to match this. The estimated cost for any new project should be assessed and costed against a specific context and end user requirements.

2.7.3.1 Fixed and variable costs

Fixed costs: some deliverables have a lower threshold that defines a minimum expenditure, (e.g. at least two site visits are required, whether you are planning to install 10 devices or 200 devices). They do not scale down past a certain base, regardless of the size of site, the number of deployed devices (or gateways), or the complexity of a site (e.g. topography, soils, vegetation, irrigation requirements)

Variable costs: some deliverables may vary in cost relative to one or more variable factors that define a project (e.g. total number of sensing devices required). Some deliverables can also have fixed and variable components to them (e.g. if a custom mounting solution is required for sensing devices, there will be a fixed cost for designing, approving, testing and setting up fabrication, regardless of the number of units required – but fabrication will then be variable by number of units).

2.7.3.2 Cost of project establishment

Variable costs for project establishment relate to contextual factors such as end user requirements (e.g. site priorities for function and impact), size of area (which tends to correlate roughly with the size of the sensing device network), geographic spread of locations, complexity of the site(s), stakeholder engagement requirements (e.g. with business and the community), and the complexity of data analytics. It is not well understood which of these variable factors will have the most impact on project establishment costs.

Furthermore, any new context will require some degree of customisation and adaptation of the SIMPaCT solution (e.g. fieldwork requirements, capture of unique local metadata). It is not clear how much work is required by a project team to adapt the current demonstration version of the SIMPaCT Solution to a new context. Neither is it clear how much work would be required to adapt a more mature but generic version of SIMPaCT to a new context. All these unknowns should be investigated as part of SIMPaCT 2.0[1] pilot projects.

This means that the fixed costs of project establishment will provide the most direct guide to a minimum possible cost of project establishment, and in turn defines the minimum probable scale for a project. Based on scaling SIMPaCT through replication of the pilot project to medium and large scales, Table 3 outlines fixed variable costs and illustrates their range and complexity. This reinforces that there is a probable low end to the scale of replication as even the smallest version would still require most of the costs identified. Explanation of this assessment is provided in a more detailed table in Appendix C.

Table 3 A summary of fixed and variable capex for project establishment

Establishment costs	Fixed	Variable
Project management		
Project management	Y	+
IoT system design and integration management		
IoT system design and integration management	Y	+
Collation/production of technical documentation	Y	+
Sensing devices		
Procurement	Y	
Sensing devices (hardware, configuration, and onboarding)		Y
Additional mounting hardware: custom mounting infrastructure extensions (e.g. masts); custom mounting solutions (e.g. brackets and connectors)	Y	+
Device communications (assumes LPWAN[2])		
Procurement	Y	
Communications hardware (gateway hardware, gateway configuration)		Y
Communications service (year 1 – consider this to be an establishment cost as it is required as part of establishment activities)	Y	
Gateway deployment planning and approvals	Y	+
Gateway installation	Y	+
Sensing device network planning and deployment		
Sensing device network planning and approvals	Y	+
Sensing device installation	Y	+
Management and oversight of the deployment process Verification and troubleshooting of devices and data	Y	+

[1] See Chapter 6 on scalability pathways for more detail regarding proposed SIMPaCT 2.0 projects

Establishment costs	Fixed	Variable
Device management and technical support during project establishment phase (to support activation, verification and troubleshooting)	Y	+
Sensing device network documentation	Y	+
Metadata		
Metadata schema adaptation	Y	+
Metadata capture	Y	+
Platforms and services		
License fees (year 1)	Y	
Platform/model instantiations	Y	
Platform hosting	Y	+
Database establishment and customisation	Y	
Irrigation management platform customisation	Y	
IoT platform customisations	Y	
Data management platform customisations	Y	
Biophysical model training	Y	
Dashboard creation and first year of hosting (optional)	Y	
Operationalisation and handover		
Workflow integration	Y	
Training of irrigation contractors and land owner	Y	

Table 3 assumes the site already has automatically controllable irrigation infrastructure in place, as a prerequisite for SIMPaCT. If not on site, its procurement and installation is an additional cost component for the landowner.

Insights relating to the cost of project establishment

The cost of establishing SIMPaCT at new sites, in new contexts, is a major consideration for its scalability and future success. However, the estimation of accurate establishment costs is very difficult, as it is highly contextual.

Pilot projects are not good indicators of future cost of establishment. The first SIMPaCT pilot project at Sydney Olympic Park (SIMPaCT 1.0) was an experimental multi-million dollar undertaking. It entailed a large number of partners trialling and testing approaches, developing the method, and building the infrastructure. As a proof-of-concept project design and experiment it was an inefficient process compared to a possible later iteration of SIMPaCT, so its establishment costs cannot be used directly as the basis for costing future project establishments. With the technical design of the SIMPaCT digital twin now in place, it can be replicated for a new project at a lower cost (conditional on the as yet unknown levels of additional custom development required for integration with new irrigation management systems). Costs may also reduce over the next several iterations of SIMPaCT as the methodology of the solution matures, enabling a more efficient overall delivery.

However, while we can reasonably anticipate establishment cost reduction relative to the pilot project, it seems likely that there will be a lower threshold. Although it is nearly impossible to place meaningful figures on such an estimate given the large number of contextual variables, in Appendix C there is an attempt to quantify a possible cost range for a future SIMPaCT, following the general structure and approach of the SIMPaCT 1.0 pilot project. This indicates that the lowest possible cost will probably be in the order of several tens of thousands of dollars.

2.7.3.3 Cost of operations

A preliminary assessment of the annual cost to operate and maintain SIMPaCT 1.0 suggests a range of $70,000 to $120,000 in 2023 pricing. This is for a 40 hectare site with 200 soil moisture sensing devices, 50 temperature and humidity sensing devices and 13 weather stations. The low end of the range is for a minimalist approach that does not cover more complex maintenance requirements and may not be a sustainable over the long term. The upper end of the range allows for additional desirable aspects such as extra support and maintenance and ad hoc costs for repairs as needed and may be closer to the 'true' operational cost for this scale of system.

As with the cost of establishment, estimates based upon a pilot approach may be understood to be significantly higher than a final streamlined operational cost that may be achieved with a more mature business case. Furthermore, we can expect the cost of operations to reduce relative to site and device network scales. However, as with the minimum cost of project establishment, there will be a lower threshold for this, defined by a combination of fixed costs. Table 4 outlines fixed and variable operational costs. Explanation of this assessment is provided in a more detailed table in Appendix C.

Quantification estimates also provided in Appendix C suggest that possible minimum operational costs might be half that estimated for the pilot project.

Table 4 A summary of fixed and variable annual costs for ongoing operation of the SIMPaCT digital twin

Operational costs	Fixed	Variable
Administration and oversight		
Administration and coordination of all operations - either by the place owner (e.g. SOPA), or as a service provided by a third party.	Y	
Oversight and strategic management (within place owner organisation)	Y	+
Device communications (assumes LPWAN with private gateways[4])		
Account/network service fee p.a. (Maintenance of the gateway/s and the IoT network including periodic upgrades to maintain connectivity to evolving network standards, rectification of faults, configuration updates and remote monitoring and alerting)	Y	
Per/Gateway management fee p.a	Y	+
Dashboard and Visualisation Tool (50 Devices) fee p.a.	Y	+
Network server access fee p.a.	Y	
Sensing network operations		
On-the-ground management (Physical day-to-day management of deployed hardware, including: checking status reports, fault diagnosis and troubleshooting, firmware updates, reconfiguration, battery replacement, decommissioning, replacement, re-location, metadata/documentation updates, liaising with tech support and place owner)	Y	+
Annual technical support fee for each device vendor (troubleshooting support, over the air updates, return to base, fix/refurbish)	Y	+
Auditing and reporting	Y	+
Periodic workflow and training updates	Y	
Metadata and documentation management		
Updates to system metadata (Constant updates are required to ensure system functionality)	Y	+

Operational costs	Fixed	Variable
Platforms and services		
License fees p.a.	Y	
Platform/Data hosting	Y	+
Biophysical model operation (p.a. service fee) (Twice-yearly calibration and validation, data quality assurance, model updates relating to in-park hardware adjustments, etc.)	Y	+
Dashboard hosting	Y	

Insights relating to operational costs

High operational costs are not sustainable over the long term. Given constrained public budgets, this will particularly be the case if local governments and public institutions are the likely future users of SIMPaCT. Indeed, SOPA has not been able to justify covering the current operational costs for the SIMPaCT 1.0 digital twin in the immediate post-pilot period, however it will be supported the NSW Department of Planning and the Environment so that the system remains active for at least one additional summer after the official end of the pilot project, to ensure that data is collected over a hot dry period (forecast for 2023/24). This will be vital for proving the true performance of the solution.

To succeed, a strategy must be found to reduce the minimum achievable operational cost. Many of the more significant fixed operational costs of SIMPaCT, such as platform hosting and licensing, do not scale at all within the range of a very few to hundreds of devices[2].

[2] Operational cost efficiencies for IoT platforms and services tend to only emerge at the scale of many thousands of devices. Variation between say, 10 and 500 devices in a network, will make no difference to the baseline capacity and service that must be provided and paid for.

3 ENQUIRY FOR SCALABILITY

3.1 An overview of the scalability enquiry

Chapter 3 documents investigations of the context into which a future SIMPaCT will fit, and the understanding that this offers for the design and direction of a future SIMPaCT. Areas of enquiry include:

- **Smart cities.** There is a review of the emerging smart city field, the trends, definitions, and prerequisites for scaling such projects, which gives a guide to what the future of SIMPaCT may look like. Case studies of other smart city irrigation projects were reviewed to see if they offer lessons in this respect.
- **Commercial irrigation control products.** To understand how SIMPaCT can succeed in a commercial context the commercial market for irrigation control systems was reviewed to understand the products with which it will have to interface, where the market is heading, and how SIMPaCT is different from the systems the market currently offers.
- **Future users.** The enquiry examines the context of possible future users of SIMPaCT to understand motivations and impediments for future implementation. To be viable SIMPaCT will have to offer what end users want and are prepared to pay for.
- **Sydney Water** has contributed a statement on its view of the future of the irrigation sector, which advances a direction for a future SIMPaCT.

When the findings of this enquiry are combined with the pilot project insights, the project team is in a position to make reasonable, informed judgements about SIMPaCT's growth possibilities and what scenarios are most viable for scaling SIMPaCT, in order to recommend a path forward.

A Scability Working Group was established within the research project to provide the high-level framework for this enquiry. Working group members discussed the opportunities, were interviewed separately for their expert perspectives, and critically reviewed draft propositions. The working group was led by UTS Institute for Sustainable Futures. Members were senior representatives from project partners: SOPA, Sydney Water, WSU, DPE Water, Eratos, and HARC.

3.2 Context reviews

3.2.1 Emerging smart city trends

3.2.1.1 An overview of emerging trends

If the initial phase of the smart city era (broadly speaking, the 2010s) was dominated by standalone pilot projects (KMPG Australia and Public Sector Network , 2019; Kummitha & Crutzen, 2017), then the current emerging phase for smart cities is a shift towards scaled solutions, defined by large-scale data sharing and aggregation, and digital twins (Deng et al., 2021; Hämäläinen, 2020; Kandt & Batty, 2021). This global trend brings with it significant opportunities and challenges (Russo and Feng 2020).

Large-scale data sharing and aggregation refers to any effort to support widespread sharing of data into a central repository, generally managed by a public entity, for the purpose of big data analysis. The trend emphasises the removal of 'data silos' and the unlocking of powerful new value (Quek et al. 2023). It may relate to sharing within organisations, between multiple organisations, and across multiple industries.

A digital twin is a virtual representation of a place or area that is connected to multiple real-time data sources and runs over an extended and ongoing period. It supports the investigation of complex relationships between multiple systems and processes, and the simulation of 'what-if' scenarios. Digital twins can operate at a variety of scales. The current technical aspects of the SIMPaCT solution are defined as a digital twin, however digital twins are increasingly being developed at much larger scales such as metropolitan and state (see case studies below).

A digital twin simulation will often bring together the outputs of multiple parallel models for specific sub-systems such as weather, pollution dispersion, traffic congestion, crowd movement, energy demand, and urban planning. Machine learning may be used to improve a digital twin over time. We can therefore understand SIMPaCT as a digital twin and consider it relative to a veritable explosion of larger-scale digital twin projects in Australia and globally.

3.2.1.2 Case study examples

City-scale digital twins: Hobart, Darwin

Major cities in Australia and around the world, are developing digital twins as large-scale data aggregation platforms that are expected to deliver major economic benefits and support a diversity of data-driven impacts.

The Greater Hobart Digital Twin is already delivering direct benefits in areas such as city planning, rooftop solar, tree management, road maintenance, fire-fighting, sewage and plumbing upgrades, and walking track maintenance.

The Darwin Digital Twin has been developed as a city-wide planning tool with a focus on aggregating and modelling large quantities of data about urban heat, air quality, tree canopy cover, the 3D built environment, and socioeconomic data. The twin allows city planners to explore the relationships between the urban environment, public health and community amenity.

The Endeavour Energy engineering grade digital twin

Endeavour Energy is an energy utility company operating electricity networks in the west of Sydney, Hawkesbury and Blue Mountains. The Endeavour digital twin has been developed to optimise the operation of 12,000 kilometres of power lines and 160,000 poles, and has already proven itself as a valuable tool during bushfire and flooding emergencies, winning multiple awards for its impact.

State-scale digital twins: NSW and VIC

The New South Wales and Victorian State Governments are both investing in the development of state-wide spatial digital twins. These are designed as the hubs of federated ecosystems of smaller digital twins; for example, a Bathurst Digital Twin, which operates separately but is closely integrated with the NSW platform. This federated approach will likely see the integration of multiple city-scale twins, as well as various specialised twins (e.g. for transport, planning, energy, etc.) in the coming years.

OPENAIR: Air quality data aggregation for local government

OPENAIR is a project that works with local governments to develop capability around the use of low-cost air quality sensing devices, supported by the NSW Department of Planning and Environment. The project has developed a data aggregation platform that supports the sharing of real time air quality data from local governments, into a centralised state-managed platform. Shared data will be combined with state government data sources to improve air quality modelling across the state, which will support improved public health information and more informed planning and operational outcomes across a number of sectors.

Heart of the Nation national data aggregation network

Heart of the Nation maintains 247 Automated External Defibrillators (AEDs) across Australia. IoT technology connects all units in their network in real time, helping to ensure that units are present and functional. Large networks of connected devices, that support optimised central operations at city, state or national scales, will become ubiquitous in coming years.

3.2.1.3 The significance for SIMPaCT

From this review it can be seen that SIMPaCT is entering a world of very large scale digital twins, data sharing and aggregation, with sufficient previous examples to prove that the technological is capable of sustaining the scale and complexity involved. Although SIMPaCT could remain as a small scale stand-alone digital twin this would miss the opportunity for high impact that a large scale aggregated data model could present.

3.2.2 Smart city project scalability

3.2.2.1 Types of scaling for smart city projects

In a seminal paper on the scalability of smart city projects, van Winden and van den Buuse (2017) outline three types of scaling for smart city solutions: roll-out, expansion, and replication (Table 5).

Table 5 Scaling types

Scaling type	Description	Manifestations	Examples
Roll-out	Brining smart city solution to the consumer or business-to-business market, or applying the solution in the entire organisation	Market roll-out Organisational roll-out	Smart energy meters introduced in consumer market; system for car sharing implemented in municipal organisation
Expansion	Add more partners, users, or functionalities to a smart city solution, or enlarging the geographic area in which the solution is applied	Quantitative expansion Functional expansion Geographic expansion	Add functionalities or partners to a tourist smart card system; enlarge the geographic area of a smart lighting solution
Replication	Replicate (exactly or by proxy) the solution in another context by the original partners involved in the pilot project, or by others	Organisational replication Geographic replication	Replicate a tested vehicle-to-grid system in a new part of the city; replicated a smart traffic light solution in another city

3.2.2.2 Factors that affect smart city project scalability

The same van Winden and van den Buuse (2017) paper presents six factors that affect the scaling potential of smart city projects, summarised in the following, together with reflections on if and how SIMPaCT addresses those factors and what they may mean for SIMPaCT's ability to scale. These have been used to inform our approach to scaling SIMPaCT.

FACTOR 1: Prospects for economies of scale

- **The project has good prospects for economies of scale**

  The project is designed in such a way (technical, governance, business models, etc.) that it has the potential to achieve economies of scale following the pilot phase.

- **There is potential for Network Scaling**

  Network scaling is where the value of a product or service increases with the number of users. It applies to many large-scale technology-based services and platforms, where access to more data improves functionality and outcomes for everyone.

FACTOR 2: Management of ambidexterity

- **Capacity for ambidexterity**

  The capacity of the lead organisation for management of ambidexterity[3], and the degree to which the pilot project is designed with ambidexterity in mind. This often aligns with:

  - there being a team and/or staff positions within the lead organisation(s) that are dedicated to smart cities, IoT, innovation or similar topics, allowing effective strategic focus on how to manage and leverage innovation processes.
  - there being effective governance and operational frameworks in place for strategically managing internal innovation and exploitation processes during and after the project.

FACTOR 3: Knowledge transfer mechanisms and incentives

- **The requirement to produce and share knowledge transfer materials**

  The project will produce and share knowledge transfer materials that cover all aspects of the project (strategic design, technical design, governance, finances, stakeholder engagement, etc.). Should include critical analysis and reflection, and discussion of next steps, scalability, etc.

- **Project complexity minimisation and collective knowledge transfer strategy**

  The project is designed to limit or optimise complexity, in order to support better tacit knowledge transfer. This includes optimising the number of project partners and keeping the relationships between partners as simple as possible. For projects built around multi-partner consortia, collective knowledge capture and transfer strategies should be evident.

- **Internal knowledge sharing capacity**

  There is capacity for sharing and leveraging knowledge generated by the project, within the lead organisations, to support value extraction and scaling. This includes the existence of effective institutional frameworks for the internal transfer of knowledge.

- **External knowledge sharing capacity**

  There is capacity for sharing and leveraging knowledge generated by the project, outside of the lead organisations. This includes the networked status and profile of the organisations, particularly their connection to other government organisations, to industry and research, and to other urban areas and jurisdictions, and their capacity to make use of those connections.

[3] The concept of organisational ambidexterity comes from business management literature and relates to the process by which the value that emerges from innovation is effectively exploited and embedded into an organisation's standard operations. Central to this is the recognition that the core competencies required for innovation are different to those required for exploitation, and that a balance of the two (i.e. ambidexterity) is necessary (March 1991).

FACTOR 4: Regulatory, legal, and policy frameworks

- **The connection of a project to aligned internal ambition**

  The degree to which project activities are supported within an organisation by aligned internal ambition. Formal policy and strategy carry the greatest weight, though alignment with parallel projects and activities, as well as less formal commitments via organisational membership of groups is also of relevance.

- **Sustainable local public funding and a balanced exposure to external market forces**

  The capacity for ongoing financial sustainability of the initiative at a local government level, after the pilot phase.

  The degree to which the project is exposed to or shielded from external market forces, in order to protect and incubate innovation while ensuring that activities remain grounded in market reality. A well-designed pilot project should provide an optimal balance between exposure and shielding to support the best scalability outcome.

- **The cross-jurisdictional policy environment and a balanced exposure to the external policy and legislative environment**

  The degree to which the project is easily scalable between local governments, regionally, and to state and national level, with respect to external policy, legislation, regulation or standards that may either support or hinder it. This includes a consideration of the stability and maturity of the external environment itself (e.g. are there clear policies and standards in place?), and the design of a project in terms of its reliance upon that environment for scaling success. This factor also relates to the exposure of a project to (or shielding from) the external policy and legislative environment during its pilot phase.

FACTOR 5: Data and systems interoperability

- **Organisational commitment to data sharing**

  Any formal commitment by the project or lead organisations to sharing project data beyond the team of project partners. This includes open data release and other forms of managed inter-organisational data sharing.

- **Technical capacity for data sharing and systems interoperability**

  The technical capacity for data sharing and systems interoperability is emphasised, including best practice system design and data and system management approaches, and the capacity for establishing an atmosphere of trust and mutual collaboration between data users.

FACTOR 6: Standards to measure Return on Investment (ROI)

- **Relative market maturity of the technology**

  The maturity of the technologies as a complete integrated and functional system that can be applied reliably in an operational context.

  'Maturity' relates to: the operation of technology itself; the legal, policy and standards environment that supports the technology; the associated business models required for scaling the technology; and cultural readiness for uptake, use and trust in the technology.

  At a simpler level, this concept relates to an estimation of how 'experimental' and ‘innovative’ a project is, versus how 'operational' it is.

3.2.2.3 Significance for the future of SIMPaCT

For SIMPaCT, we can consider these three scaling types to apply as follows:

Rollout	The strategic scaling up of the SIMPaCT solution across the whole irrigation market; and/or bringing SIMPaCT as a systemic solution across the whole of Sydney Water, tied to deeper strategic priorities
Expansion	Enlarging SIMPaCT across Sydney Olympic Park, and potentially to nearby locations, with the addition of adjacent local government partners.
Replication	Standalone copies of SIMPaCT at new sites, involving some or all of the original partners

The vision presented for SIMPaCT in this roadmap primarily aligns with **rollout** and **replication** models of scaling. Replication aligns with creative commons and licencing scenarios as well as with direct copies. The vision is less reliant upon expansion activities and van Winden and van den Buuse note that in many successful examples of rollout, the original pilot project served as an initial testing environment but was dissolved during the scaling stage. This supports the idea of continuing the Bicentennial Park project for at least a year of operations to collect test data.

Factor	Reflections for SIMPaCT
Prospects for economies of scale	This factor suggests that the long term success of SIMPaCT may require that it strategically pursues and achieves economies of scale. Scalability enquiry should include consideration of these prospects. The concept of network scaling, if applied to SIMPaCT, would resemble a subscription-based data service associated with a larger-scale digital twin, allowing the cost-per customer to reduce as the size of the network increases.
Management of ambidexterity	The SIMPaCT coalition of partners, with its diverse expertise, demonstrated ambidexterity capabilities with respect to a broader agenda beyond Sydney Olympic Park. Ambidexterity relating to technology innovation and value capture within the context of SOPA is less developed, which creates challenges for maintaining or expanding the pilot system. This factor suggests a need for IoT/smart city expertise within the organisations responsible for longer term rollout of SIMPaCT (most likely NSW DPE and Sydney Water). It also suggests that long term involvement of the NSW Smart Places team and UTS ISF could be beneficial, due to both institutions having strategic expertise in these areas. This all supports an argument for independent review by Sydney Water and NSW DPE (as the major big picture stakeholders) of the current smart irrigation technology landscape in Sydney and NSW, and strategic positioning relative to that technology in order to capture the maximum possible value of SIMPaCT and of broader emerging innovation in the space.
Knowledge Transfer Mechanisms and Incentives	SIMPaCT has excelled in the production of detailed best practice knowledge transfer materials. These will be critical for supporting future scaling success. SIMPaCT is complex and features a large multi-partner consortium. This is a challenge for scalability. However, good governance has ensured effective collective knowledge capture and transfer by the end of the pilot phase, which should help to support flexibility going forward. Efforts have been made to ensure internal knowledge sharing within the core coalition at the end of the SIMPaCT pilot, helping to ensure that partners are aligned. This supports a foundation for scalability. Between the core SIMPaCT partners, extensive strategic networks and partnerships are evident, that will be critical to future scaling success. These networks are already being actively engaged. This factor justifies a focus, post-pilot, on building a community of practice around smart irrigation, and holding events that support this (e.g. a roundtable for the wider community of stakeholders).
Regulatory, Legal, and Policy Frameworks	This factor supports the idea of key leadership organisations (e.g. NSW DPE and Sydney Water) establishing internal policy positions on the critical concepts behind SIMPaCT (e.g. the role and future of smart irrigation and its intersection with critical challenges like climate change, resource management, and urban density). Established internal policy is likely critical for long-term strategic engagement with SIMPaCT as a scaling solution. This factor relates to the degree to which a pilot project is shielded from a broader regulatory, legal and policy landscape, and to what extent that landscape will create scalability challenges. It is unclear how this will impact SIMPaCT's scalability prospects, however it is clear that the pilot was indeed shielded in this way. It is understood that affordability and accessibility can help to reduce these challenges, meaning that these should be prioritised as part of a future vision for the solution. Finally, this factor supports a specific focus on understanding and engaging with the policy and standards landscape for smart irrigation.
Data and systems interoperability	SIMPaCT was built for interoperability and data sharing between diverse systems (not just the ones featured in the pilot). This places it in a strong position for future scaling. This factor emphasises that commercial models built around interoperability and large-scale data sharing stand the best chance of successfully scaling.

Factor	Reflections for SIMPaCT
Standards to measure ROI	Despite significant initial success, with the pilot system proven to work in a functional sense, there is still a great deal of maturing needed around operations and workflow integration, legal/policy and standards alignment, business model development, change management and upskilling, and the realisation of reliable and sustained positive impact. Return on Investment is currently difficult to assess for SIMPaCT. An analysis of the solution's performance over the summer of 2023/24 should provide more clarity about the best ways to measure ROI. However, it should be noted that these may well vary between sites and place-owners. While direct financial benefits (e.g. savings related to water efficiency) are simple enough to measure, many of the social and environmental benefits of SIMPaCT are much harder to measure. Social wellbeing from improved public amenity, or public health benefits from localised cooling are certainly outcomes of strong interest to place owners, however it is currently difficult to accurately measure them as known outcomes of SIMPaCT and incorporate those measurements back into a clear ROI report. As we seek to build business cases for SIMPaCT going forward, this will present a challenge.

3.2.3 Other smart city irrigation projects

3.2.3.1 An overview of other smart city irrigation projects

This research undertook a literature search for smart irrigation systems comparable to SIMPaCT, to understand how unique or otherwise this project is, and to see if there are lessons that might help to define its value proposition, suggest a future direction, or distinguish SIMPaCT in the market.

Smart irrigation systems using the Internet of Things (IoT) are an emerging technical development and many studies have been published in recent years. However, most literature focuses on agricultural applications, while application to urban parks or urban spaces is still quite limited.

Only two comparable case studies were found in Australia, one in Cairns and the other in the City of Perth. Both of these projects were partly funded through Federal government grant funding. Published material provided no information on whether there was any intention or attempt to scale the projects to other locations or towards a commercialised solution. They appear to have tested their approaches as stand-alone research projects.

From a review of global literature, one case study in Barcelona (Poblenou Park Centre) and one case study in a tourist resort in Faro, Portugal were found.

3.2.3.2 Case study examples

Smart Watering System for Cairns Parklands, Cairns, Queensland

With funding from the Federal Government's Smart Cities and Suburbs Program, researchers from Central Queensland University collaborated with Cairns Regional Council and Rain Bird Australia to optimise urban irrigation using artificial intelligence, the Australia Research Data Commons Nectar Research Cloud and the Internet of Things. The project objectives were to:

- Improve and optimise irrigation in two of the city's parks
- Minimise chemical runoff into waterways and Great Barrier Reef
- Reduce water consumption in all Council irrigation systems
- Manage and program Council irrigation systems more effectively
- Adapt to the workload of park employees
- Ensure parks are healthy and green all year round for the community to enjoy.

An ET (evapotranspiration) program, which was Rainbird IQ software that combined data including weather, soil types, vegetation types, sprinkler type and precipitation rates, fed into an automated irrigation control to optimise the amount of watering. It gave the vegetation type an amount of water that allowed the roots to 'chase' the moisture in the ground rather than being overwatered. If done well this approach results in healthier vegetation.

The project used a Dual Electromagnetic (DUAL-EM) sensor to scan the parkland to visualise the distribution of moisture content in a contour map helping to identify the locations of interest to install moisture sensors to build the park's real- time watering profile. The IoT system used a Low Power Wide Area Network (LoRaWAN) to connect moisture sensors (MP640), and micro-weather station (ATMOS 41) to automate the data collection. To optimise the computer model, the live data of the IoT system were combined with field data (e.g., infiltrometer data, sprinkler dispensing rate, soil texture, etc.) and lab test data (soil moisture content, soil salinity, bulk density, etc) into a machine learning algorithm which would learn by time to improve the prediction. A sap flow meter in a selected tree provided transpiration losses of trees, improving the Rainbird system irrigation prediction.

Challenges faced included managing a new type of system with wide range of stakeholders and rigid time frames, and resolving proprietary issues when integrating new inputs into the Rainbird software.

Outcomes were a more efficient use of water through better design and programming; better ability to manage and operate the systems with remote login capabilities; and better ability to monitor the irrigation systems and measure consumption through the installation of sensors and weather stations, which allowed for comparisons, tracking and further improvements.

This information was extracted from multiple sources (ARDC, 2021; Australian Government, n.d; Chandrappa et al., 2020; ICT International, 2020).

The City's Smart Irrigation Control system, Perth, WA

The Perth project was part of the City of Perth's smart city innovation program. With matched funding from the Federal Government's Smart Cities and Suburbs Program, the project was a city-wide large scale roll out of 106 smart irrigation devices covering 120 hectares of parks and gardens. They replaced traditional irrigation and integrated into the City of Perth's live management systems through the RainMAN SCADA based Central Control Platform. The new irrigation sensors used predicted weather forecasts and soil moisture readings to automatically adjust watering. During rainfall events of more than 2mm the central control automatically shut down all irrigation systems to conserve water. Staff utilised a remote-control app to improve maintenance efficiency and could pause irrigation events or make changes to irrigation schedules after hours if needed for sporting or social events in the parks. Environmental monitoring was further enhanced through the deployment of a series of water and air quality sensors across greater Perth.

The project's objectives were to be a systematic, efficient and cost-effective approach to addressing water management and usage in the face of a forecast hotter and drier climate. It aimed to demonstrate water, electrical and operational savings, and reduced nutrient runoff. During the 2020/21 financial year 229,329,000 litres of water was conserved, or a 27% water saving in the City's total groundwater budget. (Aquamonix, 2019; Australian Government, n.d. ; City of Perth, n.d.)

Poblenou Park Centre, Barcelona, Spain

In 2014, the City of Barcelona invested in moving 178 of its irrigation points to an IoT controlled irrigation system to reinforce its Smart City status. Its objectives were to optimise irrigation water consumption according to weather conditions and plant needs. The system is controlled remotely using tablets, computers and smartphones and uses information from sensors and weather stations to optimise plant watering. The management system allows automatic control of the electronic valves that close or open the water flow. In-ground sensors offer live data on soil moisture. Humidity, temperature, wind velocity, sunlight and atmospheric pressure are recorded above ground. It enables gardeners to decide which plants need based on the data, and adapt their schedule to avoid overwatering. It enabled up to a 25% saving of water. (Laursen, 2014; Libelium, n.d.)

Vale do Lobo, the Algarve, Portugal

At a tourist resort in Vale do Lobo, in the Algarve region, Portugal, the Green Space with Smart Irrigation System project includes 154 small gardens with 20 installed irrigation meters, which water a neighbourhood of villas with turf grass and flowerbeds. A smart irrigation system was installed in the beginning of 2019. It is connected to a meteorological station located in Faro and to a platform that determines the irrigation needs according to local weather conditions. It automatically controls hourly the amount of water that is supplied by the irrigation system, shutting off the system if no irrigation is needed. The turf grass area is irrigated with sprinklers (Rain Bird, series 5000) and the flowerbeds with drip-irrigation. The project objective was to optimise irrigation efficiency in green space by an accurate estimation of plant water requirements in order to minimise excessive watering. (Monteiro et al., 2021).

3.2.3.3 Significance for the future of SIMPaCT

The projects that were found in this review demonstrate the interest in using sensors and predictive data to optimise irrigation, with similar objectives to SIMPaCT of a combination of water efficiency and plant health, although they do not mention urban cooling as an objective or outcome.

The Cairns project is the only example uncovered by this research that uses a machine learning approach. Although technology familiarity or maturity may play a role in this absence, local climate may also be significant. In climates where rainfall, or lack of it, is seasonally reliable, weather forecasts may be sufficient to achieve the desired outcomes. As an example, irrigation requirements in Perth are not considered by the SIMPaCT team to be comparable to Sydney because Perth has a drier climate needing regular summer irrigation whereas Sydney's subtropical climate has intermittent and less predictable irrigation needs, which is what is addressed by SIMPaCT. As climate change progresses, we expect that the geographic range of unpredictable rainfall will increase.

Although there are signs of technology advancement in the sector, SIMPaCT appears to be alone in applying machine learning to an irrigation control system that aims to create urban coolth. It also appears to be alone in attempting to scale the experimental version to become a central element in the local irrigation landscape with ambition to expand and deliver it benefits well beyond.

3.2.4 Commercial irrigation systems

3.2.4.1 Overview

There is a broad spectrum of irrigation control technologies available in the market. Most of these systems operate with a focus on water use efficiency. Real time and automated irrigation systems have demonstrated potential for water savings and some of the major providers are taking these advancements to the next level by adding predictive modelling features to improve climate resilience. This section is a scan of the commercially available technologies, and the most common and emerging features of smart irrigation.

Study of the grey literature and product specifications reveal that a few providers are dominating the market, due to the range of technology options they offer. Some of these major players include Rainbird Corporation, Hunter, Aquamonix, Lilbelium, Waterwise, Think water, OneWiFi, Arduino, Orbit, Toro, and Galcon. The products of other providers like Irritol, Dragino, Easy irrigation, Jeffery have fewer options and less flexibility. The baseline offering in most of the products available today is low cost sensors connected to automated controllers through wireless communication technology, with a basic level of weather forecast integration. Providers like Orbit, Irritrol, OneWifi offer connectivity through WiFi and/or Bluetooth. Some of the major providers like Rainbird, Hunter, Glacon and others offer a range of connectivity options like long range connectivity or LoRaWAN, making them more popular in areas where flexibility of technology is required or that are remote from communications services.

Monitoring of environmental parameters is gaining significance in the context of changing climate and unpredictable weather events. Products from providers like Hunter, Rainbird, Libelium and Aquamonix have controllers with manual or automatic operation that are connecting to low-cost sensors monitoring parameters including soil moisture, humidity, temperature, and evapotranspiration. The controls either stop or delay/adjust irrigation scheduling depending on weather conditions by using data from both the sensors and weather station. Similarly various communication technology options are also offered by many providers that can be made 'fit for purpose' and can be both- cost effective as well as water efficient at the same time.

Table 1 gives a quick comparative overview of some of the key features prevalent in the products currently available in the market, determined through a scan of the company websites and product specifications.

Table 1 Overview of smart technology offered by major providers in the Australian market. Those shaded in dark green indicate the features of an advanced system. SIMPaCT uses a Fieldmouse irrigation control platform.

Features \ Providers	Hunter	Rainbird	Galcon	Aquamonix	Libelium	Waterwise	Orbit	OneWifi	Arduino	Dragino	Easy irrigation	Irritrol	Jeffery Electronics	Fieldmouse
Communication technology														
Wired/USB	√								√				√	√
WiFI	√	√		√	√	√	√	√	√	√	√	√		√
LoRaWAN					√				√	√				√
4G					√									√
5G								√						√
Radio												√	√	√
Bluetooth				√	√		√		√		√			√
Cellular transmission/SIM cards			√								√			√
Controllers														
Manual		√									√			
Automated	√	√		√			√	√	√	√	√	√	√	√
Weather integration														
BoM or internet based	√	√	√	√	√	√	√	√				√		√
Scheduling management														
Alerts and notifications	√			√			√	√	√	√		√		√
Scheduling timeframes						√		√						√
Daily	√		√	√	√	√					√	√	√	√
Calendar/selecting days of the week		√		√		√								√
Event based	√	√							√			√		√
Up to a week	√		√			√		√			√			√
Week or more		√									√			√
Logic Control														√
Predictive modelling > 2 weeks	√	√		√	√	√								
AI and Machine learning features				√	√	√								
Cloud data storage	√	√	√	√	√	√		√						√
Data analysis		√		√	√	√	√							

Broadly, these systems can be categorised into 1) Basic and 2) Advanced (as indicated in Table 1 by the dark green shading). With the rapid advancement in smart irrigation technologies, the existence of low-cost sensing-based irrigation can be categorised under 'Basic' offering. Providers like Rainbird, Hunter, Libelium, Aquamonix, Think water, OneWiFi and many others offer these at a reasonably competitive price. Irrigation scheduling or decision-making for water allocation based on the network of controllers and sensors is offered by most providers that allows the entire irrigation system to stop if rain or snow is detected. This feature is most common as it avoids over watering, protecting plant health and optimising water use.

The following features are the point of difference between basic and advanced products and are still on their way towards wider penetration in the market:

1. Long term predictive modelling (more than 2 weeks in future)
2. Machine Learning and Artificial Intelligence
3. Cloud based data storage.
4. Data analysis, data visualisation and interpretation support
5. LoRaWAN technology

Based on the literature and product specifications available on their websites, Libelium, WaterWise and Aquamonix are the only companies who have advanced features in their commercial products.

While major providers like Rainbird, Libelium, Waterwise and others provide the basic features, some of their premium products have the ability to run predictive modelling and learn from the data injected into their systems. For example, Hunter offers advanced sensor-based features and local weather integration functionalities to assist with predictive watering and can adjust long term water scheduling. Hunter applications provide integration with solar radiation and temperature and uses Evapotranspiration (ET) to determine the correct seasonal adjustment percentage value to send daily to the controller based on local weather conditions (Hunter). Similarly, WaterWise, a model developed by CSIRO is a water-use efficiency product for high value irrigated crops that measures crop water stress and predicts future water needs in real time. In-field sensors measure the canopy temperature of crops every 15 minutes and are combined with weather forecasts in a data infrastructure. The model applies this information to its algorithm to predict the crop's water requirements for the next seven days (CSIRO, 2020). Providers like Aquamonix and Libelium have the capacity to complement the existing smart irrigation infrastructure with artificial intelligence interfaces, UAV (unmanned aerial vehicles, also known as drones) and remote sensing techniques to support decision making.

Data gathered from sensors requires analysis and interpretation to makes sense and to optimise the irrigation system according to the weather conditions. Cloud based data storage and data analysis thus is emerging to becoming more common than what it was a decade ago. Providers like Irritol, Easy irrigation, Dragino, Arduino have some products that offer this service. Providers like Aquamonix, Libelium and Orbit offer end to end solutions that include support with interpreting data, managing data storage on cloud and also customised data reporting. They also provide an app-based service allowing remote controlling of the irrigation system.

Fieldmouse, from CTS, is the irrigation control portal used at SOP to which SIMPaCT connects. In discussion with CTS they indicated that Fieldmouse has the capability of including all the advanced features identified above and is open to integrating data and connectivity with other providers. They advised that they do not offer the predictive modelling, AI, ML or sensor connections because these features are cost prohibitive for their client base, which is predominantly LGA-owned sports fields. Instead, they use logic control for scheduling and water management.

Advanced irrigation products respond dynamically to changing weather, with the resulting action to simply skip one or more scheduled irrigation events. However, when an irrigation system truly learns, as does SIMPaCT, it not only dynamically responds to changing weather, it also responds to changing plant needs (as a tree grows, for example it may need more or less water). The soil moisture sensors ensure that regardless of how water demands are changing, the correct water balance can be maintained.

The knowledge of climate responsive irrigation control is emerging and there is still a clear gap in the available literature that documents in-depth analysis of smart irrigation systems available in the market today and what are they capable of (Garcia L, et.al 2019). However, considering the rapid deployment of technology in the market and incremental advancements in the IoT based systems overlayed with the changing climate, it is evident that smart and climate responsive irrigation solutions that are not only technologically advanced but can also offer impact flexibility will dominate the market soon.

3.2.4.2 Significance for the future of SIMPaCT

Our market scan found that commercial irrigation control products are becoming increasingly smart, using cloud-based data analytics and responding dynamically to changing environmental conditions, with the incorporation of soil moisture data and weather forecasts.

The SIMPaCT digital twin, with its advanced analytics models and machine learning capability, is more sophisticated than these commercial products. SIMPaCT also balances a focus on plant health and water efficiency with optimised urban cooling; a capacity that is not present within any commercial solutions. These factors currently provide SIMPaCT with a point of difference advantage. However, this advantage is narrowing as the leading companies increase the functionality of their products.

SIMPaCT requires a baseline smart irrigation system in place that it can interact with and issue commands to. SIMPaCT is therefore an add-on to smart irrigation. If there is little difference between SIMPaCT and the smarter commercial products then SIMPaCT does not represent enough additional value to landowners to justify the extra cost when added the base system. In that case, there will not be a proposition on which to advance SIMPaCT as a commercial product.

Against a backdrop of climate change, worsening urban heat and increasing water scarcity, there is likely to be growing demand for smart climate-responsive irrigation solutions, and the commercial ability to meet that demand is growing. In short, SIMPaCT may soon find itself facing competition from the very systems that it needs to integrate with in order to function. Ideally, the current points of difference of SIMPaCT would generate additional value for commercial providers, turning them from competitors into willing collaborators, although as reinforced by CTS, the benefits of the additional costs would need to be clear.

The purpose of this Roadmap investigation is to clearly define the differences and growth possibilities for SIMPaCT to determine where its future may lie.

3.3 Local government perspectives

3.3.1 Engagement process

To understand who potential future users of SIMPaCT may be, and their needs and limitations, potential regional and metropolitan local government stakeholders were consulted. Local governments were the focus of the interviews because very few other large scale parks and gardens irrigators could be identified by the project team. The team interviewed five metropolitan and two regional LGAs and a peak water body with a local government focus, as representative of the sector to provide insights that could be applied across the sector. The officers who were interviewed had responsibilities ranging across strategic planning, open spaces, city services and water management, sustainability and resilience.

The interviews were conducted as conversations one-on-one or in groups, with the focus on charting the settings in LGAs or any other organisations, that allow innovation or uptake of water management strategies. The aim was to understand the motivations and impediments that would drive conditions for a future SIMPaCT.

The methodology, interview participants and questions are summarised in the Appendix.

3.3.2 Common themes and insights

3.3.2.1 Common settings

Although local governments priorities and focus areas may vary annually based on their financial, social, economic and development goals, the interviews found that there were settings that were common to encouraging the uptake of water management strategies or solutions like SIMPaCT.

Existence and ownership of large green open spaces, sport fields, recreational parks within the LGA and community expectations for their upkeep and amenity

Local government areas having a number of large open spaces coupled with a strong community expectation to keep them alive, accessible and green, can be a conducive setting to consider a solution like SIMPaCT.

Local governments recognised the importance of maintaining green open spaces like public parks, sports fields, golf courses and racecourses within the LGA. The positive contributions made by these spaces towards enhancing social cohesion, elevating mental health and physical wellbeing are acknowledged by communities, particularly since the pandemic. Three metropolitan LGAs reported that there is an increasing expectation from their communities to maintain these open spaces and keep them available and maintained for community use all year long.

Most green open spaces and sporting fields are Council owned assets, with developer ownership being an exception in one LGA. LGAs use various irrigation and other water management strategies to keep these assets accessible and green. LGAs in the metro region that have a number of large sporting fields or open spaces use a combination of automated and manual irrigation, however, two LGAs reported that the use of automation is much less prevalent and is often unmaintained or underutilised where it does exist. Limiting factors are the lack of resources and staff, technical knowledge and skills, and availability of budgets for maintenance of the infrastructure. In most of the Councils interviewed, potable water is used for irrigation, followed by other sources like reservoirs or river water where available. Because of the cost to transport water from the treatment plant, recycled water is used less often by regional LGAs.

Four LGAs reported that local government is responsive to community expectations and action, which has motivated some to a more proactive approach in managing water and the assets in general. Examples include sending messages to communities on water levels or water use across the local area based on real time data, to increase community awareness of water. LGAs are more willing to take that extra step in managing their open spaces, where community awareness on climate change, urban heat and drought is relatively high. Two of the LGAs reported that they had community action groups that demanded maintenance of the sporting fields and green open spaces as a prerequisite for their wellbeing.

Naturally available sources of water for irrigation or locational advantage

Geographical settings play a notable role in the way water is managed and distributed across the council owned assets. Proximity to naturally available sources of water like rivers and reservoirs is seen as a huge advantage and a key driver towards implementation of tactical integrated water management solutions. In the regional LGAs, where water is from multiple sources like reservoirs or nearby rivers, irrigation is more regulated. Moreover, the need for controls for switching according to the availability of water from each source drives irrigation automation and optimisation so it occurs more in these settings compared to locations where irrigation is dependent on a single source. However, there is still some degree of manual intervention to assist the automation.

In one LGA, there was a clear differentiation where river water is allocated for irrigation and bore water for drinking. Rainwater harvesting and water storage is undertaken by LGAs on a small to medium scale that includes water harvesting for large international sports fields as well as large developments for two LGAs. Generally harvesting rainwater with filtration systems installed and using it for irrigation is seen as a huge cost where the return on investment is considerably low. Where LGAs are also the water authorities, they understood the benefits of upgrading their current systems to fully automated ones based on their experience; the presence of formal documented policies were not prerequisites to initiate action. On the other hand, three LGAs that were not a water authority themselves reported that they are more reluctant to take action, as budgets in these cases are often driven by priorities outlined in Council policy instruments like strategic planning or other environmental policies.

The availability of multiple sources of water allows local governments to irrigate their sports fields and recreational areas more regularly. Where automating irrigation systems for integrated water management was seen as a positive, solutions like SIMPaCT could assist in optimising water from these sources.

Existing policies or programs

Implementation of tactical water management solutions in some LGAs is seen to be agnostic of any formal policy or overarching program. Local governments that have historically faced natural disasters like drought, particularly displayed strong willingness to not just effectively manage water but also explore the path of automation and water management strategies around irrigation. This was also true for LGAs who were their own local water authorities. In other cases, water management or irrigation strategies seemed to have a direct link with the Councils' formal policy instrument. For example, in two LGAs, efficient water management (that included irrigation) was linked to one of the chapters in Development Control Regulations on urban heat and climate change.

Initiatives that stem from policies or programs that link to the LGA's strategic planning take priority over initiatives that are separate from policy. Financial decisions, annual budgets and resourcing is largely aligned with these priorities. For local governments to consider solutions like SIMPaCT, formal policies around water management or overarching climate change policies that indicate the need to efficiently manage water could be leveraged to argue for investment in efficient irrigation. In other cases, historical events like droughts could trigger consideration of implementing SIMPaCT. Most local authorities lack a full suite of water management and efficiency, water sensitive urban design, urban heat, and climate resilience policies. Where these topics do come up, they tend not to be widely integrated across policy areas. This lack of foundational policy at local scales will not readily support investment in SIMPaCT, particularly during the early adoption phase. Siloed work practices mean decision crossing departmental lines will need internal resolution and therefore be harder when there is a poor policy basis.

Governance issues also affect the possibility for SIMPaCT, needing commitment at a senior level, or advocacy by Councillors, and dedicated staff time and interest to pursue it. Willingness to pay and prioritise this expenditure (capital and operational) would need a strong business case (for return on investment). It would also need to fit within limitations of operational plans that identify activities for the next 3-4 years. Thus, to argue for investment, it is important to understand what problem SIMPaCT can help to resolve, and the current financial and resourcing capacity of the Council.

The LGAs mentioned that infrastructure grants are large and commonplace and may offer a funding source if establishing SIMPaCT can be rolled into a larger project such as a significant place upgrade (e.g. major civil works in a public park) or the establishment of new precinct.

Pre-existing technology and automation

Most Councils that were consulted had a certain degree of automation in managing water through irrigation, but not smart enough to host SIMPaCT. The degree of automation depended on factors like resourcing, budgets and also operational expenses required to maintain these systems. Some metropolitan councils used soil moisture probes and water meters to schedule irrigation, whereas others installed smart meters. Two LGAs reported that they were not using them effectively due to absence of dedicated staff to maintain or troubleshoot if required, difficult access to the meters, and budget constraints. Local governments installed systems like Rainbird, Hunter and Galcon to optimise water use. Not all the systems were cloud based, with some technologies dependent on manual operations and so failed to introduce efficiency in the operations of the system. In some cases, automation was implemented over smaller geographical areas, and restricted to locations like the centre of the town. Councils were keen to consider solutions like SIMPaCT where it was either complementing existing systems with no or minimal added costs, or was linked to existing and approved water management strategies as part of overarching strategic planning. Ongoing maintenance costs, operational challenges and lack of skilled personnel with the know-how of smart technology are some of the challenges for LGAs to pursue solutions like SIMPaCT.

Working with technology requires learning and change so adoption of technological solutions like SIMPaCT may not necessarily be an obvious solution or a priority. One LGA questioned the value addition of SIMPaCT and the cost benefit, including return on investment; the added value of a more complex system would need to be very clear for LGAs to take it up. This is particularly relevant for LGAs that are resource and budget poor. Many may also struggle to recruit relevant staff or upskill existing staff to operate and maintain the installed technology. LGAs with some experience in automation will be more open to upgrade their systems and consider solutions like SIMPaCT. There may be an opportunity to leapfrog to SIMPaCT via major infrastructure upgrade initiatives, particularly with state or federal government grant funding to assist where the LGA recognises the value .

3.3.2.2 Drivers for the adoption SIMPaCT

The consultations explored existing and overarching organisational strategic initiatives or policies on water management within local governments that may drive adoption of SIMPaCT.

Agendas and budgets in local governments are often based on the strategic plans or political landscape, with community expectations also playing a role. In most cases, if one of the Council's priorities is water conservation or water management or if these priorities directly derive from Council's local policy or strategic instrument, then the chances of Council being open to considering innovative solutions to drive the agendas forward was high. Where the local water authority is the LGA itself, resolution of water management issues occurred comparatively faster, as the decision making lies solely with the organisation. This can be an advantage when proposing a solution like SIMPaCT.

Findings from the consultations indicate that the existence of a formal policy instrument is not a prerequisite or a motivator for the uptake of technological solutions. Councils that had implemented tactical water management solutions had either experienced a historical event like drought or it was an outcome of the vision of council leadership that led to the implementation of technology. Additionally, local governments that have a pressing need to conserve water from a 'resource sustainability' point of view, are those likely to consider solutions like SIMPaCT irrespective of existing policies.

3.3.2.3 Value for local governments

With increased awareness and concern around climate change and urban heat, LGAs realise the need to provide more water for communities, new developments and to keep green infrastructure alive. LGAs acknowledge their reliance on potable water for irrigation of parks as a problem, and is not sustainable. Increased community awareness around the role of green open spaces and public parks in maintaining their health and wellbeing will increase pressure to irrigate and the cost of supplying potable water is expected to rise many folds in the coming years given this increasing demand.

The biggest value proposition for LGAs to adopt SIMPaCT will be to optimise water supply to communities as well as parks and open spaces and sporting fields whilst keeping the costs low. Achieving water efficiency outcomes like detection and management of leaks, and scheduling irrigation based on weather conditions are examples of some immediate wins.

SIMPaCT can address other environmental goals like reducing dependency on groundwater, improving data tracking or scheduling irrigation that in turn can help maintain irrigation infrastructure. The machine learning component of SIMPaCT can help prioritise water allocation, take water conservation decisions and reduce costs from unnecessary or over supply of water. SIMPaCT can also be used as a planning tool by local governments to design irrigation infrastructure and assist developers in designing new developments by avoiding over engineering of the irrigation infrastructure.

As extreme heat events become more common, the ability of SIMPaCT to offer cooling benefits efficiently will become increasingly attractive, especially to LGAs with vulnerable communities.

The algorithms of SIMPaCT can be tailored to make the model 'fit for purpose' and smarter which adds value for LGAs. Positioning SIMPaCT as a bespoke solution to manage overall water demand and irrigation infrastructure can make a strong business case for local governments.

3.3.2.4 Change management within local organisations

Operationalising SIMPaCT represents a major change to existing operations for most new users. Resistance to change, and the process by which new technology becomes embedded and normalised, may frustrate success during early adoption, particularly in the early years where projects may be characterised as pilots. As the SIMPaCT pilot demonstrated, co-development with the end user builds trust in the product and means the solution is fit for purpose. A well-designed governance model and defined role responsibilities with strong support for staff from the development team will also smooth the way.

3.3.3 Opportunities for SIMPaCT within local government

Opportunities within local government emerged from stakeholder conversations and indicate a range of possible applications for SIMPaCT, including some beyond a direct replication of the current installation.

3.3.3.1 Large developments

LGAs with population influx and with large developments that include precincts, airports etc. may be able to source funding through infrastructure grants or developer contributions. LGAs that have planned large developments in their areas have the option to work with developers and encourage adoption of smart water management techniques. When developers have some experience with cloud-based automation, smart meters, faster connectivity like 4G, or LoRaWAN they are more likely to consider SIMPaCT as a retrofit solution. In such scenarios, the initial investment of installing SIMPaCT should be low compared to the overall development cost, allowing flexibility to adapt SIMPaCT based on existing requirements, scale and site conditions.

3.3.3.2 Multiple water sources

Regional Councils with some experience with automation in the management of water may offer good opportunities, particularly where there are multiple sources of water (dams, rivers, reservoirs etc.) for irrigation that need to be managed and scheduled.

In cases where Councils use automation to switch between primary and back-up water sources, switching between those sources was not necessarily automated and relied on manual intervention. Although commercial providers like Rainbird or Hunter can provide automated, Wifi based controllers to undertake the switching, SIMPaCT can add value through its predictive modelling and machine learning for short- medium term decisions to manage water more smartly without needing manual intervention.

3.3.3.3 Flood mitigation

One LGA suggested SIMPaCT may help with risks of over-watering or flood mitigation. When heavy rainfall events are predicted the LGA needs to empty stormwater reserves prior to the rain event in order to free detention and retention capacity.

3.3.3.4 The SIMPaCT value propositions

The four main value propositions of SIMPaCT benefit LGAs very directly:

- They need to maintain the quality of UGI for public amenity and urban cooling in order to benefit community physical and mental wellbeing.
- The water efficiency SIMPaCT delivers will help to mitigate rising water costs.
- As more irrigated space is required, the cost of effectively managing it will increase

3.4 The Sydney Water perspective

3.4.1 The engagement approach

Selected members from the SIMPaCT project team were interviewed to ensure their experience and expertise were reflected in the analysis and recommendations. Their knowledge and advice have informed the Roadmap throughout.

However, with responsibility for the water supply for the whole of the Sydney metropolitan area, Sydney Water has a very special perspective on what the future may hold. In addition to contributing input throughout the entire enquiry process, the project's Sydney Water strategic adviser and member of the Scalability Working Group, Andre Boerema, Sydney Water Service Planning Lead, has contributed the following position statement.

3.4.2 A position statement on smart irrigation

As Sydney grows the need to meet increasing water demands become more complex when intertwined with increasingly dynamic climatic conditions. There is an overall imperative to ensure per capita demand for water continues on a downward trend over the medium to long term.

There are no new water resource options for Sydney which will put downward pressure on water supply costs. In other words, as the city expands the marginal cost to supply increased water needs will increase with each period of expansion. The impact of this set of circumstances is simply that it will increasingly become more financially attractive to use water efficiently, at all times.

The Western City's growth during a period of climatic warming implies that irrigation for cooling will steadily become more essential. Sophisticated irrigation control systems that have the ability to learn and constantly adapt to the water demands of complex, growing landscapes will need to prevail if we are to ensure that no more and no less water is used than is necessary to effectively address UHI impacts.

During periods of drought-induced water stress historically, restricting outdoor water use has presented the greatest, lowest cost way to rapidly reduce water demand. This approach has been remarkably successful through the course of several major periods of drought resulting in rapid and remarkable reductions in per capita water demand [Figure 4 below:].

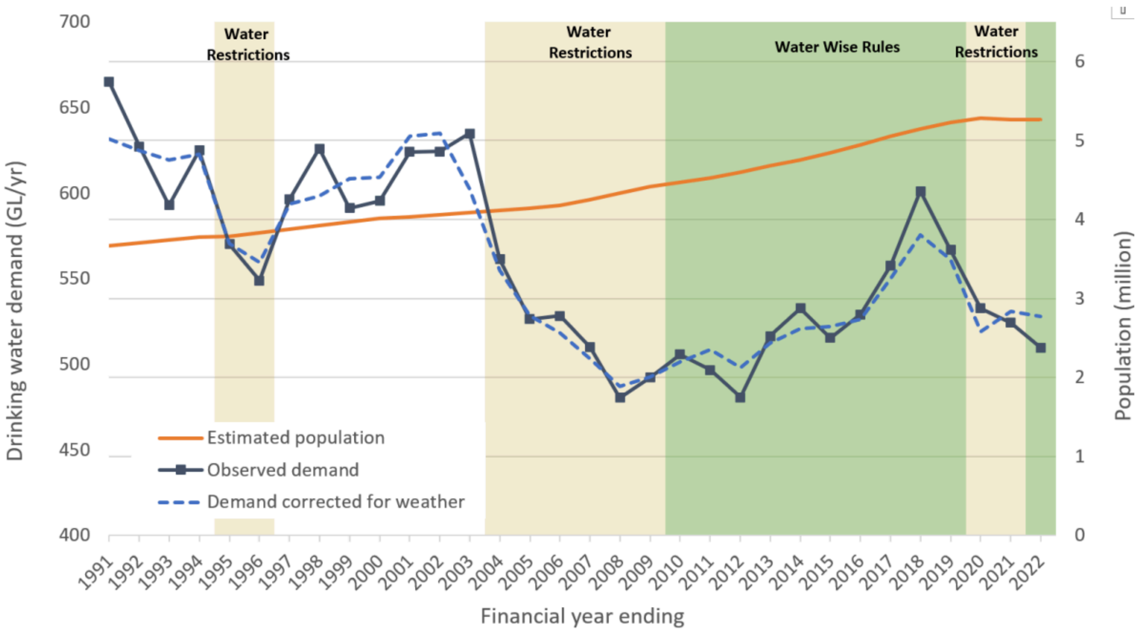


Figure 4 Demand for drinking water (Observed and weather corrected in gigalitres) and population growth over time. Source: Sydney Water (2022)

The weather correction plot in the chart above shows how much higher peak demand can grow during periods of severe drought. On a more micro, daily scale and at individual water supply zones, these peaks are even more dramatic and this underpins a capacity and cost challenge for Sydney Water. Peak day and peak hourly demand are what water supply systems must be designed to satisfy. In practice, these 'peaks' routinely coincide with the hottest days of the hottest months of the year, which may only occur a handful of times a year, but which drive a great deal of expenditure to satisfy (iPART).

Irrigation demand is thought to be a significant contributor to these peaks, in several supply zones. As Western Sydney expands and the climate warms, it's not inconceivable that Sydney Water will need to take an increasing interest in how to best manage the UHI impacts on Western Sydney while also balancing its need to contain costs and meet prevailing water demand, even during periods of severe drought.

Knowing that irrigation systems for the largest parklands in a given supply zone are able to ensure irrigation and UHI mitigation needs are met outside of forecast peak demand periods is just one obvious way that SIMPaCT level irrigation sophistication may offset the risk presented by the confluence of challenges associated with peak demands, a warming climate and a growing Western Sydney region.

Regionally, that is beyond the boundaries of the two large, coastal state-owed water utilities in NSW, the water supply costs during periods of water scarcity tend to escalate more rapidly and severely, meanwhile community desire for usable sports fields, healthy, green parks and respite from heatwaves is no less important than in Western Sydney.

Once again, these conflicting objectives of irrigation control can best be resolved with a sophisticated solution that adjusts dynamically to prevailing and forecast conditions, ensuring potentially decreasing water budgets are always utilised to maximum possible benefit.

Even during periods of no water supply stress, the majority of the State's water supply is from fixed storages, meaning the more demands that are supplied to highly efficient end uses, more water remains in storage, for longer.

4 A HIGH-LEVEL VISION AND STRATEGY FOR THE FUTURE

This chapter of the Roadmap introduces a high-level vision for scaling SIMPaCT, including a series of general goals that might be pursued. It considers a series of opportunities as well as major challenges, based upon insights from the pilot project and the broader scalability enquiry. Finally, a series of strategies are recommended for achieving the high-level vision.

4.1 Establishing a high-level vision for scaling SIMPaCT

A high-level vision helps to define what scaling the SIMPaCT solution means. It establishes a set of common goals that can then be pursued through various strategies and scenarios.

The high-level vision for scaling the SIMPaCT solution has been defined through articulation of six aspirational goals. The goals are arranged in a rough order of priority, meaning that goal 1 is assumed to be the most fundamental to the scalability vision, and goal 6 is assumed to be the most aspirational.

Each goal is intended as a potential possibility that is also desirable to achieve. Chapter 5 of this Roadmap explores five scaling scenarios for SIMPaCT. Each scenario has the potential to deliver on the high-level vision by supporting some or all of the six goals. The goals provide a means of comparing scenarios in terms of their ability to deliver on a common vision. These goals are not intended to be absolute, meaning that achieving each of them within any given future scenario is optional.

Table 6. An overview of the six goals that make up the high-level vision for scaling SIMPaCT

	Goal	Description
1	Widespread use	The widespread use of the SIMPaCT solution, or a future iteration based upon it, defined by a large and growing user base.
2	Adaptable solution	A flexible and adaptable solution, evidenced by its deployment in a wide variety of contexts, serving a wide variety of end user requirements.
3	Sustainable and resilient business case	A sustainable and resilient business case that ensures ongoing viability and growth across a wide range of deployment contexts and users.
4	Affordability and accessibility	Affordability and accessibility of SIMPaCT as a solution that benefits everyone.
5	Public good	The ongoing and expanding delivery of public good with respect to urban cooling, water efficiency, public amenity, and improved management of Urban Green Infrastructure; in the face of worsening climate change.
6	Public leadership	Active public leadership relating to smart water management

4.1.1 Widespread use

4.1.1.1 What do we mean by widespread use?

The widespread use of the SIMPaCT solution, or a future iteration based upon it, defined by a large and growing user base

This is the most fundamental goal for a high-level vision of scalability as it defines what we mean by scale itself. It is clear from our enquiries that there is widespread interest in SIMPaCT and its value propositions, and that the solution has the potential to deliver value in many places, for a large number of place-owners. Scaling success should be defined by the degree to which SIMPaCT is adopted by a large and growing user base. It could be measured by the total number of users, as well as total land area managed. It is not concerned with *diversity* of users or sites.

4.1.1.2 Importance

Widespread use is important because it is the basis for widespread impact creation. The value propositions for SIMPaCT are all systemic; while urban heat, water scarcity and public amenity are certainly localised concerns, they are also very much large-scale ones. If SIMPaCT is widely adopted then these issues can be addressed at a more systemic level, at the scale of cities and regions.

Widespread use is also key to achieving economies of scale, which may position it as a fundamental pre-requisite for achieving other goals such as a self-sustaining business case, affordability and accessibility, and the creation of public good.

4.1.1.3 How SIMPaCT could achieve widespread use

Widespread use requires that many organisations see value in the SIMPaCT solution, and that the cost of establishing and operating SIMPaCT is outweighed by measurable return on investment. To achieve this, the high-level value propositions of SIMPaCT likely need to be refined into more specific measurable deliverables that are tied to things like financial reporting, internal and external policy, or compliance. The cost of access to SIMPaCT also needs to be reduced as far as possible, with recognition that most place-owners are extremely cost-sensitive. Specific opportunities, financial and legal mechanisms and incentives may also be considered to help tip the balance of the cost-to-value equation (e.g. subsidies, rebates, special dispensations, carbon offsets), suggesting possible government leadership.

The interoperability, supportability and scalability of the SIMPaCT digital twin, and in particular the Senaps platform, mean that the system could readily scale to support a large user base. This includes the possibility of larger multi-site digital twins that service multiple users at once. High interoperability means that SIMPaCT can be easily and cost-effectively adapted to integrate with a variety of commercial irrigation management systems.

4.1.1.4 Key challenges of achieving this goal

The greatest challenge is cost of establishment and cost of operations. These costs will be highest in scenarios involving stand-alone instantiations of the SIMPaCT digital twin. Larger multi-site instantiations that operate using a subscription model have the potential to reduce costs on a per-user basis.

Collaboration with commercial irrigation suppliers is likely to be the second greatest challenge. The SIMPaCT digital twin is currently configured for integration with the Fieldmouse irrigation management system. It can be integrated with other smart irrigation management systems, however this requires a degree of custom development by both parties, which in turn requires collaboration. SIMPaCT needs to articulate a clear value proposition to commercial providers to ensure that such collaboration occurs. Many of these providers have systems that already deliver some of what SIMPaCT does. The benefits of adding SIMPaCT to an existing smart irrigation system need to have a clear business rationale that vendors can readily sell to their clients at an acceptable cost.

The value proposition of SIMPaCT is still somewhat theoretical. Even assuming it is proven in principle (from a summer of data collected from its operation in Bicentennial Park), that value needs converting into measurable business cases that work for place owners. This maturation of business cases can really only be achieved by subsequent rounds of SIMPaCT pilot projects (2.0 projects) that explore and refine the focus and measurable deliverables of SIMPaCT in new contexts. Assuming success, the learnings from this second round of pilots would form the basis of more widespread rollout.

4.1.2 Adaptable solution

4.1.2.1 What do we mean by an adaptable solution?

A flexible and adaptable solution, evidenced by its deployment in a wide variety of contexts, serving a wide variety of end user requirements.

An adaptable solution should be applicable across diverse contexts, and able to deliver different kinds of value based on diverse end user requirements. Adaptability relates to the design of the solution (notably how well it can be practically integrated and operated in a variety of contexts), as well as the way in which the solution delivers value.

4.1.2.2 Importance

It is clear from our enquiries that there are a broad range of potential applications for SIMPaCT, distinguished by diverse types and sizes of site, types of place-owner, and different sectors. To ensure the greatest chance of scaling and widespread use, SIMPaCT should seek to deliver diverse value across these different contexts, and to do this it must be adaptable.

Adaptability is also critical for ensuring that SIMPaCT can maintain a point of difference form commercial irrigation systems that are increasingly delivering or seeking to deliver the same types of value as SIMPaCT. These systems are not only in direct competition with SIMPaCT, they are also necessary foundations for SIMPaCT to run, making them simultaneous collaborators and competitors. Adaptability ensures that SIMPaCT can evolve to the changing commercial landscape and continue to identify and capitalise on unique value propositions, ensuring ongoing viability.

4.1.2.3 How SIMPaCT could achieve adaptability

Adaptability should be built into the design of the SIMPaCT solution. The design focus should be interoperability with diverse irrigation management systems and data sources; something that the SIMPaCT 1.0 system has demonstrated. The focus of the value proposition also needs to be adaptable to different clients and business contexts. Where one client may prioritise water savings, another may prioritise public amenity or cooling. SIMPaCT needs to be able to be configured to emphasise different outcomes.

4.1.2.4 Key challenges of achieving this goal

The key challenge to the adaptability of SIMPaCT is its reliance upon integration with an existing smart irrigation management system. This limits the types of locations and contexts that it can be deployed in. For example, a majority of green space that is managed by local government does not have an existing smart irrigation system in place. The need for this kind of integration ties SIMPaCT to the agenda and needs of the commercial providers, which may hinder its adaptability.

4.1.3 Sustainable and resilient business case

4.1.3.1 What do we mean by this?

A sustainable and resilient business case that ensures ongoing viability and growth across a wide range of deployment contexts and users.

In many ways, this is the definition of successful scaling. A sustainable business case may be purely commercial, where a direct income generated through the provision of services exceeds the cost of delivery (e.g. annual costs saved through water efficiency and improved management outcomes exceed the cost of operating SIMPaCT). Alternatively, sustainability may be tied to the delivery of public good, where a sustainable public subsidy covers any shortfall between direct income and cost of delivery, based on measurable or perceived public benefit. The second scenario might apply to local government use of the system; for example, running SIMPaCT at a slight loss, justified by the improved provision of public amenity.

Resilience relates to the ability of a sustainable business case to be maintained. For example, if market conditions or public policy were to suddenly change, a more resilient business case stands more chance of continuing. This goal is therefore about ensuring that the SIMPaCT solution continues to be viable and grow, regardless political or market changes.

4.1.3.2 Importance

A sustainable and resilient business case goes hand-in-hand with adaptability for ensuring the widespread use of SIMPaCT over the medium to long term. Disruptions and challenges from the market and in the public sector should be anticipated and planned for.

4.1.3.3 How SIMPaCT could achieve sustainability and resilience

A sustainable and resilient business case is almost universally achieved through an iterative development process. SIMPaCT has only ever been deployed in one context and the business case for continuing it in that context is not clearly established (beyond the need for short term collection of experimental data, justifying NSW DPE support). In order to develop a sustainable and resilient future business case that is also adaptable to a wide variety of contexts, SIMPaCT must be deployed in more places, with a variety of different partners (place-owners, irrigation providers, etc.). This will deliver practical experience and a pathway for iterative development of a more sustainable and resilient business case.

A sustainable and resilient business case relates to the demonstration of measurable value that exceeds the cost of investment. This equation needs to stack up for all stakeholders, including the place-owner (who is investing directly), any public funding body that might by subsidising or incentivising investment, and the commercial irrigation providers (that may be in direct competition).

An adaptable design may be a critical attribute of the SIMPaCT solution that supports the development of a sustainable and resilient business model. It means that a large number of deployment contexts and scalability scenarios can be explored to determine the most promising pathway.

4.1.3.4 Key challenges of achieving this goal

The key challenges are commercial competition, and the volatility of public sector support.

Commercial competition reduces the range of options for value delivery to points of difference. A reduced value proposition increases the burden of cost. Essentially, as competition increases, the cost of establishing and operating SIMPaCT needs to fall, placing strain on a business case. We can expect direct commercial competition to increase over the coming years, potentially quite rapidly, resulting in an increasingly narrow point of difference and a pressure to consistently reduce the cost of SIMPaCT. The cost of SIMPaCT is already quite high relative to our understanding of what most place-owners can afford or are prepared to pay, making this challenge even greater.

It is quite possible that a long-term business case for SIMPaCT involves some sort of public sector subsidy, justified relative to a measurable return of public good[4]. This would be vulnerable to changes in government or policy, or to public sector funding cuts; scenarios that are likely to occur over the coming years. This is not an argument for avoiding public sector support. However, it does suggest a need to embed that support as deeply as possible into longer term strategies and policy, and to take the time to co-develop public sector business cases with public organisations. For example, section 6 of this Roadmap (pathways for scalability) suggests that Sydney Water should investigate its position relative to an emerging smart irrigation system and establish a clear strategy relating to this. Such work would theoretically underpin the support of

[4] Note that this type of ongoing public support is distinct from grants and seed funding of research and development. It is essentially a sustainable business case with a positive cost-benefit analysis, that aligns with government priorities and includes public investment.

SIMPaCT by the water utility at a strategic level over the longer term and may provide a degree of resilience to more surface-level political and market fluctuations.

4.1.4 Affordability and accessibility

4.1.4.1 What do we mean by affordability and accessibility?

Affordability and accessibility of SIMPaCT as a solution that benefits everyone.

An affordable SIMPaCT solution ensures that it is accessible to people and organisations in a wide variety of places, ensuring more widespread use and equitable experience of benefits. Affordability relates to the total cost of ownership, and for many place owners the amount that they can afford (for system establishment, and for ongoing operations), is considerably lower than minimum estimated costs for the smallest instance of SIMPaCT as a standalone system (see section 2.7.3 for discussion of costs). Accessibility includes affordability, but also a range of other constraints such as access to starting capital, staffing capacity, and the presence of existing irrigation infrastructure capable of supporting SIMPaCT.

4.1.4.2 Importance

Discussions with various local government authorities have confirmed that there are many potential applications for SIMPaCT at small scales, in urban parks and sports fields. It is highly adaptable in its design and can deliver value across multiple impact areas including water efficiency, UGI management, urban cooling, and climate resilience. However, the existing model for SIMPaCT, defined by the pilot project at Bicentennial Park, suggests a standalone model that is recreated for each new site. As explored in previous sections, a single instantiation of SIMPaCT requires a minimum site size relating to a baseline cost of ownership that does not scale down past a certain size. While we do not know what the smallest scale is, it seems likely that it will exclude many smaller sites (small urban parks, individual ovals, median strips, etc.). This makes SIMPaCT inaccessible to many local governments that might be interested in applying it at smaller scales.

Accessibility also matters in terms of serving the public good in an equitable fashion. Climate change already places major strain on the health and wellbeing of our communities. This is likely to worsen, and the ability to maintain healthy and well-irrigated green spaces will be critical for urban liveability. SIMPaCT can be a major new tool for achieving this. Public authorities should adopt a strategy for the future of SIMPaCT that ensures that no one is left behind in this picture. SIMPaCT must remain a viable and accessible option for any future irrigation context, not just large sites run by organisations with large budgets.

4.1.4.3 How SIMPaCT could achieve affordability and accessibility

An affordable and accessible approach to SIMPaCT requires cost of ownership to drop considerably. The conservative cost estimates for minimum cost of establishment and operation of a standalone instance appear to rule out a standalone replication strategy as one that affordable or accessible to most place owners. To achieve significant cost reduction, economies of scale must be sought.

Economies of scale will likely involve larger instantiations of SIMPaCT that can service multiple sites and customers via a subscription model. Here, fixed costs like platform fees, setup and labour can be one-offs, and variable costs can be reduced to flexible rates tied to data traffic, hosting and processing demand. Economies of scale like this are not only key to ensuring affordability but are also likely to be vital for long-term success and growth of SIMPaCT.

If economies of scale can be achieved, bringing cost of ownership down, then the minimum site size required for a viable business case would also reduce, which may make SIMPaCT an accessible option for smaller sites. Furthermore, an instantiation of SIMPaCT that serves multiple site and customers is capable of supporting multiple small sites across a wide area, potentially all running different irrigation management systems.

For maximum accessibility, it may be necessary for economies of scale to be combined with public sector support. For example, a local government with a very low budget might be able to access SIMPaCT if the cost of ownership was reduced heavily (e.g. via a subscription model) and state government support was received (e.g. a grant relating to improved water efficiency, that might subsidise upfront capital expenditure).

The design of SIMPaCT already supports the rapid development of a multi-site subscription model. Senaps is highly scalable, meaning that it can work reliably with much larger amounts of data, processing and users within a single instance. Its strong interoperability, combined with the modular design of the solution (e.g. the connector applications within the irrigation adapter module), enable it to integrate with multiple irrigation systems at once, and accept sensor data from multiple IoT platforms. There is little that would need changing to the existing design to accommodate a shift to a multi-site model.

4.1.4.4 Key challenges of achieving this goal

The key challenge of achieving affordability is the ability to reduce the total cost of ownership for individual place owners, particularly those with smaller sites and limited budgets.

Broader accessibility may be improved by opportunities to access seed funding that will cover or contribute to covering establishment costs. If this funding is public then it will need to be justified through alignment with policy goals, or through public sector return on investment (e.g. utility-scale water savings).

The absence of existing active irrigation infrastructure in a majority of urban green space is also a major challenge as it prevents easy retrofitting of SIMPaCT. However, it is clear that demand for irrigated green space is on the rise, and local authorities have indicated that infrastructure investment grants are increasingly available, particularly associated with state-significant development (e.g. Sydney's aerotropolis). It seems possible for SIMPaCT to be delivered as part of infrastructure upgrade projects that are funded through such grant programs. Regional authorities (that traditionally experience more challenges with water scarcity and drought, combined with less capacity and lower budgets) may well have a competitive advantage when it comes to accessing this type of funding.

4.1.5 Public good

4.1.5.1 What do we mean by public good?

Public good refers to the creation of positive outcomes for the public. This can include social benefits, such as improved health and wellbeing relating to cooler places and access to green space; environmental benefits, such as green spaces that are more resilient to heat and water scarcity; and economic benefits, such as reduced water demand and associated water stress, and reduced energy demand.

4.1.5.2 Importance

Public good is intrinsically tied to the core value propositions of SIMPaCT, particularly urban cooling, water efficiency and public amenity. It is likely to be a critical component of any sustainable business model. In public sector applications (e.g. SOPA and local governments), public good will be a major part of the rationale for investing in SIMPaCT. Even in cases that would appear to be entirely commercial in nature, the creation of public good can add an important social license to operate (e.g. a golf course that creates a down-wind cooling effect that benefits a residential area).

SIMPaCT must collaborate with commercial irrigation systems that are also in direct competition, which establishes a challenging tension. Articulating and leveraging public good is likely critical to the future success of SIMPaCT on a commercial playing field. Without it, the solution would be competing with existing smart irrigation products in terms of technical capability alone, using a purely financial rationale; a situation that would not favour SIMPaCT. Commercial products commonly seek to identify and emphasise any public good that they can deliver as part of their marketing and overall business case. Not only is SIMPaCT able to compete with them on these terms, but it is also able to do so very strongly. Indeed, the ability for SIMPaCT to deliver public good is arguably its strongest point of difference when compared to the commercial competition.

Articulation of public good is also critical for accessing any grants that might support future investment in SIMPaCT (e.g. local government infrastructure upgrades), and would also drive any deeper rationale for public sector support (e.g. a water utility choosing to invest in further rollout of the solution).

4.1.5.3 How SIMPaCT could achieve public good

Public good is defined through alignment with public policy, which forms the basis of public funding and support. To help achieve success in the short to medium term, SIMPaCT should seek public sector support. To do this, SIMPaCT should seek to align itself with current policy priorities in areas such as climate change resilience, resource security, public health, and infrastructure investment.

SIMPaCT has the potential to deliver unique high-value public good in certain key areas that are not accessible to the commercial sector. For example, a water utility that chooses to establish a metro-scale instantiation of the SIMPaCT digital twin may be able to use it to deliver major water and energy savings. Such outcomes would constitute major value delivery outside of the commercial space.

Whether it is state government funding for infrastructure upgrades, or investment by a public corporation in major new technology capability, public sector support for SIMPaCT is best served by establishing institutional positions and strategies relating to the topic. For example, smart technologies and the Internet of Things are seeing rapid uptake and are likely become ubiquitous parts of the water sector in the coming years, creating a paradigm shift for how water is used and managed. It behoves public institutions such as water utilities to investigate and establish a position relating to this shift, and build new strategies and policies around that position.

4.1.5.4 Key challenges of achieving this goal

The most notable challenge for achieving public good is that it demands public investment. Unless further public investment is secured, the opportunities for creating public good will be limited to a private sector agenda. While this does not rule out public good creation (as pointed out, it can be critical to supporting a corporate social license to operate), it does severely constrain options.

Securing public funding is therefore an important focus. However, local and state authorities are seeing their budgets cut and the amount of funding available through grant programs and for general operations is falling. This makes it increasingly difficult to rely on public sector cash injections as a strategy for scaling SIMPaCT. One solution may be to pursue an economic rationale for public investment that results in measurable economic benefit to the public sector (e.g. resource efficiencies and demand management). This more business-orientated approach to public good creation may be able to justify more significant and sustained investment and in turn support softer social and environmental forms of public good creation as a kind of added benefit.

4.1.6 Public leadership

4.1.6.1 What do we mean by public leadership?

Active public leadership relating to smart water management.

Public leadership refers to intentional and calculated actions taken by public organisations (in this case state government agencies and state-owned corporations) to support SIMPaCT, justified by the public good that it delivers.

The kinds of public leadership actions that would support SIMPaCT may include direct funding, the creation of new financial mechanisms that encourage investment in SIMPaCT (e.g. subsidies, rebates, etc.), in-kind support (e.g. via collaborative research and development), direct endorsement, the development of new policy positions that favour SIMPaCT, support for a growing community or practice, and support and advocacy relating to the development of new standards and best practice.

4.1.6.2 Importance

Public good does not necessarily require public leadership, but public leadership must always relate to public good and is the most effective way for public good to be created.

While public investment in SIMPaCT could occur in an ad hoc fashion, without any leadership position established relating to smart irrigation and the associated value propositions, such support would be inherently unreliable, piecemeal, and liable to end at any time. Established policy or strategy creates greater certainty about ongoing support and can facilitate research and development efforts over longer timescales that standard 18-month grant project delivery windows.

4.1.6.3 How SIMPaCT could achieve public leadership

The foundation of public leadership is the establishment of clear positions on the topic of discussion, in this case, smart irrigation and its implications for water demand and management in NSW. This goal suggests that water utilities like Sydney Water, and the NSW Department of Planning and Environment (Water division) should investigate and establish such positions. Given the scale and broad relevance of the issue in question, this would serve these organisations in ways that stretch well beyond a narrower SIMPaCT agenda.

A major attribute of SIMPaCT is the fact that all project IP is in the public domain. Even if much of the capability of the SIMPaCT digital twin exists within commercial competitor platforms (or is liable to in the coming years), this simple fact of public ownership should not be overlooked and is a powerful point of difference. Commercial technologies are proprietary and are locked away from use, collaboration and innovative applications within the public sector. SIMPaCT is not like this; it is open and available and is unique because of this. Public authorities now have the opportunity to take leadership in the emerging smart irrigation space using SIMPaCT, with its widespread critical acclaim, as a publicly owned entry point. It may well prove to be the deciding factor for success.

4.1.6.4 Key challenges of achieving this goal

The key challenges that would prevent public sector leadership that favours SIMPaCT are conflicting priorities (e.g. political attention turns elsewhere) and limited public funding. Additionally, the timeframes for meaningful outcomes are likely to exceed the short term agendas of election cycles, meaning that any positions or initiatives that do get adopted must be resilient to periodic political upheaval.

Discussions with various local government authorities have confirmed that there are many potential applications for SIMPaCT at small scales, in urban parks and sports fields. It is highly adaptable in its design and can deliver value across multiple impact areas including water efficiency, UGI management, urban cooling, and climate resilience.

However, the existing model for SIMPaCT, defined by the pilot project at Bicentennial Park, suggests a standalone model that is recreated for each new site. As explored in previous sections, a single instantiation of SIMPaCT requires a minimum site size that is likely to be at least comparable to Bicentennial Park. This makes it inaccessible to most local governments that might be interested in applying it at smaller scales.

4.2 Opportunities for scaling SIMPaCT

This section articulates circumstances that may facilitate future implementation of SIMPaCT.

4.2.1.1 Demand for active irrigation is expected to rise

Due to climate projections and shorter-term swings to El Nino, we expect that Australia will see a rise in demand for active irrigation in the coming years, leading to increased investment in state-of-the-art irrigation technologies. This will be evident in NSW, where active irrigation has traditionally been a lower concern (compared to Western Australia, for example). At commercial scales (parks, golf courses, etc.) this will see the installation of technologies from a handful of commercial providers. We will also likely see major uptake in private residences, with people turning to relatively unsophisticated off-the-shelf solutions that are rarely optimised for water conservation.

The ability to maintain healthy green public UGI (and all the social and economic benefits it generates) in the face of worsening extreme heat is of critical public interest. Irrigation will increasingly be required to ensure this.

4.2.1.2 Water demand for irrigation is expected to rise

Higher use of active irrigation means higher water demand, placing increased strain on supply and limited water reserves. This is a particular concern during peak demand conditions, when extreme heat events will result in widespread synchronous use of potable water for irrigation. Management of this demand is likely to become a major concern for water utilities.

Due to these two major public concerns (UGI management and water demand management), a well-managed approach to the expanding demand for smart irrigation is therefore also strongly in the public interest. Government must act quickly and decisively to ensure that public interests are addressed in the emerging smart irrigation space.

4.2.1.3 Infrastructure grants

Grant opportunities that are available from the NSW and Australian Governments relate to various forms of community and place-based infrastructure investment (see Table 7 for current examples). Key themes include investments that improve the quality of and access to open/green space and sports fields. A range of priority areas are targeted by different funding programs, including regional communities and special growth areas. Projects funded by these grant programs mostly require local or state government leadership, though some opportunities are open for private sector leadership.

A number of recent NSW government grant programs have no current or official future funding rounds planned, however they are indicative of future opportunities. These include the Metropolitan Greenspace Program (MGP), the Precinct Support Scheme (PSS), Places to roam, the Accelerated Infrastructure Fund (AIF), and the Safe and Secure Water Program (for regional communities).

Special infrastructure contributions (SICs) apply to state-significant precincts such as Western Sydney Aerotropolis and Sydney's Bayside West precinct. These impose a levy on developers, that can then be re-allocated to support a range of public infrastructure project that can include regional open space, and environmental conservation and biodiversity offsets.

Table 7. Current funding opportunities with the potential to support SIMPaCT 2.0 projects

	Funder	Types of project funded	Lead organisation	Funding range	Funding rounds
Infrastructure Grants: sport and recreation	NSW Government	Sports field extensions and upgrades Recreation space (e.g. playground, skate-park)	Local government School Not for profits	\$50k - \$300K	**Quarterly** Current: 31st Jul to 21st Aug 2023 Next: 27th Nov to 18th Dec 2023
Infrastructure Grants: community infrastructure	NSW Government	Multi-purpose community service or hub	Local government School Not for profits	\$50k - \$250k	**Quarterly** Current: 31st Jul to 21st Aug Next: 27th Nov to 18th Dec
Financial Assistance Grant to Local Government	Australian Government	Broad spectrum infrastructure support	Local government	Not stated	Open
Priority Community Infrastructure Program	Australian Government	Build resilient communities through the provision of social and community facilities Improve community amenity, accessibility and liveability through investment in community infrastructure	Local government State government agency	\$300K - \$80mn	Current: closes 31st Aug 2023
Investing in Our Communities Program	Australian Government	Build resilient communities through the provision of social and community facilities	Local government	\$5K - \$5mn	Current: closes 30th Nov 2023

	Funder	Types of project funded	Lead organisation	Funding range	Funding rounds
		Improve community amenity, accessibility and liveability through investment in community infrastructure	State government agency		
Community Development Grants (CDG) Programme	Australian Government	Support needed infrastructure that promotes stable, secure and viable local and regional economies. Construct and/or upgrade facilities to provide long term improvements in social and economic viability of local communities Improve social amenity, increased health and wellbeing and social cohesion by utilisation of the infrastructure by community groups	Australian businesses	Not stated	Current: closes 30th June 2026

4.2.1.4 Increasing investment in localised water harvesting and storage

The concept of the *Sponge city* was coined in the early 2000s by landscape architect Kongjian Yu. It is now a widely used term that refers to urban design approaches that increase the 'sponginess' of an urban area through abundant permeable open ground with vegetation, bioswales, artificial wetlands, ponds and lakes, and stormwater harvesting infrastructure. A connection is increasingly being made between stormwater harvesting and the ability to support localised irrigation of public green space. This supports a sponge city approach by capturing and retaining stormwater in the urban landscape.

Several examples of localised stormwater harvesting connected to irrigation systems illustrate a potential growing trend.

- The Gannon Park Water Quality Improvement Project is led by Georges River Council in Sydney's south. The project includes creek naturalisation combined with a new network of ponds, wetlands, swales and bioretention systems. The project will capture and deliver up to 26 million litres of water per year, for use on nearby playing fields.
- The Angus Creek Stormwater Harvesting and Reuse Scheme is led by Blacktown City Council in Sydney's west. The scheme harvests up to 200mn litres of stormwater per year from a creek and sports stadium complex, storing it in a series of ponds. Floating wetlands treat the water before it is used to irrigate the nearby Sportspark, which hosts 5000 events and attracts over 750,000 visitors each year. The cost of harvested stormwater from the scheme is 20% lower than the supply of potable water, resulting in significant savings for Council.
- Kardinia Park stormwater harvesting and reuse project is led by the City of Greater Geelong, with support from the Australian government. Urban stormwater from a 30 hectare catchment is harvested and stored in a 1.7mn litre underground storage tank beneath a public park. The harvested water is treated and used to irrigate three sporting ovals and the wider landscape of Kardinia Park, meeting 90% of annual irrigation water demand.

The main benefit of these kinds of project is that they enable irrigation of public green space while avoiding reliance upon potable water supply. This reduces cost of supply for local government and improves resilience by helping to ensure increased water security during periods of water restrictions. This should enable public amenity to be maintained during drought periods when it might otherwise degrade.

Such systems still require the presence of a sophisticated commercial irrigation system to deliver harvested storm water. SIMPaCT could be retrofitted onto an existing system to improve its functionality, or included as part of a new development. However the additional cost of establishing SIMPaCT would need to be justified. This may be done in two ways.

Firstly, the greatest value of a localised stormwater retention and irrigation system is likely to be realised during drier conditions, when potable water is most costly and may be subject to restricted supply. Harvested water during a dry period is not being replenished and is therefore a finite supply. Optimising its use will help to prolong the period of resilience that a site can maintain irrigated public space with no reliance on potable supply. There may be a business case where additional costs saved by not purchasing potable water offset the cost of establishing and operating the SIMPaCT enough to justify the additional expense. Less tangible public amenity benefits would also be factored in.

A second way that SIMPaCT might improve the operation of this type of system is by managing the switch between water supply (harvested stormwater versus potable). At a local scale, this can help to manage retained stormwater over a longer period, applying smart scheduling that conserves supply during drier periods and dumps water through the irrigation system during wetter periods, helping to reduce pressure on stormwater infrastructure and mitigate the risk of flooding. If scaled to a multi-site SIMPaCT digital twin that is managed by a water utility, further opportunities emerge. For example, the ability to control the switch between potable and harvested irrigation supply across multiple sites could enable a water utility to flatten a larger water demand peak, reducing strain on potable water infrastructure and potentially supporting significant water and energy savings. If a robust business case could be made for investment in such a solution by a utility, the cost of establishing and operating local SIMPaCT connections could potentially be reduced for local authorities, improving accessibility.

4.2.1.5 A window of opportunity for strategic public-sector leadership

There is currently a window of opportunity for strategic public sector leadership in an emerging smart irrigation sector. It is clear from our understanding of the irrigation market, as well as broader trends in IoT and smart cities, that water management (including irrigation) is rapidly shifting towards being digital, connected, and smart. If this transition is left solely to the commercial market, it seems likely that public interests will not be prioritised. Past examples from other sectors such as energy or buildings illustrate how a hands-off approach by government can result in an unregulated commercial control of an emerging sector that results in a plethora of unstandardised proprietary technologies with low interoperability. This can preclude many bigger picture strategic management outcomes and may significantly reduce the potential for public good creation. Unless we see public leadership focused on establishing widespread interoperability, we can expect to see this pattern repeated in the emerging smart water sector. It is possible that this could prevent the pursuit of large-scale public applications of SIMPaCT, such as the concept of a metropolitan or regional-scale digital twin.

If state authorities act now, they have an opportunity to take control of the agenda and maximise public benefit, while guiding the commercial irrigation market towards greater harmonisation. This window of opportunity will not remain open indefinitely. SIMPaCT is a high-profile project with national acclaim and two major awards. With its IP in the public domain, it represents what may be the best opportunity that the NSW government will find to take up a leadership position in this space. This may be a notable argument in favour of ongoing support for SIMPaCT by the NSW government and Sydney Water.

4.3 Challenges for scaling SIMPaCT

4.3.1.1 Minimum possible cost of ownership

Section 2.7.3 has discussed in detail why there is likely to be a minimum cost of ownership for the SIMPaCT solution, and that this will be fixed to a minimum scale of site. Standalone instantiations of SIMPaCT applied to sites that are smaller than this minimum scale cannot be achieved for a lower cost.

The minimum cost of ownership is likely to be the most important challenge for scaling SIMPaCT, as it is the most critical factor for determining a viable business case.

4.3.1.2 Constrained local government budgets

Almost all local governments interviewed had significantly constrained budgets, both for capital works investment and for core operations, and we believe this to be indicative of a more general scenario. The only exception was one local government closely associated with Sydney's new Aerotropolis, where a large amount of external infrastructure investment was available. This trend makes local government extremely cost sensitive, suggesting that for SIMPaCT to have a viable public sector future the total cost of ownership must be reduced well below that of the initial pilot. Indeed, it may prove to be the case that the minimum cost of ownership estimates (see Section 2.7.3) are high enough to rule out standalone instantiations of SIMPaCT for local governments.

A further consideration is the way that limited budgets interact with conflicting priorities. Recovery from flood, fire and drought damage often demands any available funds and makes it difficult to justify expenditure in anything deemed extraneous or experimental. Many local governments also have a backlog of water-related challenges and investment priorities, particularly in regional areas where they are directly responsible for water management. For example, interviews indicated very high leakage in town water systems, with potable water loss figures due to leaks as high as 30-50% reported for some regional towns. A major argument for investment in SIMPaCT by a local government is its ability to support potable water savings, with resulting financial benefits that might significantly offset the cost of ownership. In a context with very high potable water leakage, any investment in SIMPaCT that is based upon a ROI tied to water savings is in direct competition with investment in leak reduction. The decision might boil down to: should Council invest $100K fixing leaky pipes and upgrading trunk infrastructure, or invest that money into SIMPaCT instead? It does not seem unreasonable to assume that limited funds would be prioritised for core infrastructure maintenance, rather than for extension into what will become a new legacy asset that adds to the annual operational cost of the town's water infrastructure.

4.3.1.3 Unknown effort of adapting to new contexts

The SIMPaCT solution developed through the first pilot project was designed to meet the needs of a particular set of contextual factors found at Bicentennial Park. Deployment of SIMPaCT at a new location, working with a new place-owner and a new irrigation system will see changes to these factors. The effort of adapting the SIMPaCT solution to these new factors is currently not well understood. Insights from the scalability enquiry process (see part 3 of this document) provide an extensive overview of what these factors are and how they might relate to future versions of the SIMPaCT solution.

We can define two different types of challenge here. Firstly, there is the challenge of the adaptation itself. While the SIMPaCT solution was designed with future flexibility in mind, it seems inevitable that some adaptations will be more difficult than anticipated. It is also wise to expect new adaptation challenges to arise that were not anticipated at all.

The other type of challenge is associated with not knowing how complex a future project will be, relative to various changed contextual factors. This can be thought of as a risk inherent in SIMPaCT 2.0 project deliveries that hinders accurate scoping and costing. It can be thought of in terms of commercial uncertainty that is unavoidable during the earlier maturation phase of the solution. This type of uncertainty and risk is inherently tied to ongoing research and development and is a major reason why external funding (e.g. grant/public support) is still required for SIMPaCT 2.0 projects.

4.3.1.4 Competition with commercial irrigation systems (that are required collaborators)

Based on the market scan, it could be expected that most major irrigation systems will be smart by the end of this decade, if not sooner. With the growth of IoT, smart cities, digital twins, the increasingly ubiquitous application of big data, and the current rise of AI, this feels like a safe assumption.

Currently, only a handful of leading suppliers offer smart irrigation systems, live data integration and complex modelling. We expect this to change rapidly in the next few years. The cost of smart irrigation systems is likely to drop, becoming increasingly accessible. We can also anticipate significant developments in functionality as commercial players compete. AI may also play a role, making smarter functionality more accessible to industry, and more powerful in terms of what can be delivered.

4.3.1.5 Interoperability of existing commercial systems

Existing commercial systems are already limited in their interoperability. The formats of data supplied by system APIs may vary, and the content may be constrained. Systems may also not favour receiving commands from a third-party system. Ideally, SIMPaCT can be built to work with what is available, however there may be fundamental limits with some providers; so not all the main commercial systems can be anticipated to meet SIMPaCT's needs. Furthermore, even where integration is feasible, it always requires custom development work, which represents upfront investment by a commercial provider; investment that must be justified by expected returns.

4.3.1.6 Articulating the value proposition of collaboration for commercial irrigation providers

The interoperability challenge raises the question of how to work with irrigation providers to encourage cooperation and collaboration. The ability of SIMPaCT to increase the value of a given third party commercial technology or service will be key. To do this, SIMPaCT must offer something unique, that cannot be easily replicated through the existing research and development programs of commercial providers, and that the providers believe their customers will buy.

It should be noted that most commercial irrigation providers have existing R&D programs, which pursue technical capabilities that are seen to have market value. If the capabilities of SIMPaCT have market value then they will be desirable for commercial irrigation providers, (although in their conversation with us, CTS indicated that currently their customers would not be prepared to pay for services such as SIMPaCT). Either they work with SIMPaCT, or they choose to develop their own version of the same capabilities. Most R&D programs should be well-positioned to accomplish this, so the choice they make will more likely come down to cost and function. Firstly, it is important to consider how genuinely advanced the SIMPaCT solution really is and how far away a commercial R&D program is from being able to develop its own equivalent. If the effort to replicate it is not significant, it seems unlikely that a commercial provider would choose to collaborate when they could compete. Furthermore, an in-house alternative to SIMPACT developed by a commercial provider will likely integrate far more seamlessly with their existing proprietary system and be more flexible and open to updates that align with their core business strategy. They would also have full ownership of the capability, that can be differentiated from anything offered by competitors – something that cannot be achieved through a model where SIMPaCT is licensed to multiple commercial partners. One way around this last challenge might be to have an exclusive licensing agreement with one just commercial provider, allowing them to leverage maximum competitive advantage. However, in such a scenario, their competitors would likely develop their own independent alternatives to SIMPaCT that they would then have full control over. This would potentially put the licensee in a position where they lack increasingly important inhouse capabilities that their competitors have, making them vulnerable and ultimately leaving them at a disadvantage.

4.3.1.7 Current lack of active irrigation systems in a majority of publicly managed UGI

Interviews with local governments have indicated that a majority of urban green infrastructure within their management portfolios lacks any form of active irrigation infrastructure. This is partly because most of their managed green space is distributed across many small parks, reserves and median strips where it is difficult and costly to extend active irrigation. Active irrigation is also often missing from larger parks due to the upfront capital investment and the ongoing cost of operation.

When local governments do use active irrigation, the priority tends to be sports fields as these are most highly valued for their public amenity, with the clearest economic return on investment. Where active irrigation does exist, it invariably lacks a 'smart' management system (centralised digital control, automatic scheduling, sophisticated data management platform) that would be capable of integrating with SIMPaCT.

This all means that under current conditions, there are quite limited options for existing public sites that could host SIMPaCT. Furthermore, we know that local authorities are highly cost sensitive and are experiencing budget cuts that make direct investment in active irrigation, let alone in SIMPaCT, look unlikely in the near future.

This suggests two potential scenarios:

- Firstly, it might represent a strong push for SIMPaCT into the private sector, where a great deal of existing active irrigation infrastructure is in place. This might include golf courses, hotels, corporate headquarters and large private residences. The challenge with the private sector is that it will tend to require a more purely economic business case to support SIMPaCT (e.g. value of water saved must offset total cost of ownership), relative to public business cases which may be built more around arguments for public good creation that justify operation at a loss.
- The second scenario is that public sector demand for active irrigation is about to increase, in line with government targets for expanding high-quality green space, rising urban density, and worsening climate change. Under this scenario, we might expect to see significant public investment in new active irrigation infrastructure, driven predominantly through state and federal infrastructure grant programs that emphasise community outcomes. This presents an opportunity for SIMPaCT to be rolled into larger infrastructure projects. Indeed, it seems possible to associate SIMPaCT's water efficiency outcomes with a social license to operate new active irrigation systems, meaning that it could help to justify investment in major new projects. This success of this approach would be heavily contingent upon the operational cost of SIMPaCT remaining low enough that it can be sustained by a local government on a tight budget.

4.3.1.8 A lack of clear market or policy incentives for uptake of SIMPaCT by developers

There is a current lack of clear market or policy incentives for private sector uptake of SIMPaCT in new developments. SIMPaCT is an opportunity to deliver a range of advanced benefits that are not typically included in development control plans (DCPs). Private developers will tend to invest the bare minimum required of them by a DCP, meaning that SIMPaCT is unlikely to be considered. Furthermore, any business case for investment in SIMPaCT tends to revolve around anticipated benefits (be they financial, social or environmental) that are realised later. Developers install irrigation systems and hand them over to a new owner shortly after completion of the development (for residential developments this is often local government). There is no incentive to ensure that the irrigation system is optimally designed or has smart operations that help to reduce operational costs, because the developer will never see those benefits[5]. If a DCP requires irrigation infrastructure then the cheapest and simplest option will be the one that makes the best sense to the developer.

Some developments seek market advantage through adoption of additional design elements. An example would be the Green Building Council of Australia's *Green Star* rating for precincts. Six-star precincts gain critical acclaim that certainly translates into a direct addition of value. The rating system includes mechanisms like 'innovation points' that are designed to reward investment in emerging technologies and design approaches that are not mandated in DCPs. Voluntary ratings like Green Star may help to leverage SIMPaCT, however their uptake is relatively low and innovation points can be gained in many ways, meaning that they may only support a handful of SIMPaCT demonstration projects, rather than any sort of more scaled commercial rollout. However, this may still represent an opportunity for supporting a SIMPaCT 2.0 pilot in a new context.

4.3.1.9 Data security and privacy challenges for larger-scale digital twins

Larger-scale multi-site versions of the SIMPaCT digital twin could support a subscription-based SIMPaCT-as-a-service business model and may be the key to success in both the public and private sectors if they can dramatically reduce the total cost of access on a per-customer basis. However, such systems involve largescale data aggregation, working with multiple organisations. Any efforts around large scale data aggregation bring with them a variety of data security and privacy challenges that will need to be addressed. These challenges may be non-trivial. Deep consideration of what needs addressing is required, and should feature in an initial position paper by Sydney Water or NSW DPE

4.3.1.10 Data harmonisation and heterogenous data synthesis

A fundamental challenge for any large data aggregation platform is that diverse data sources will differ from each other in format, structure, and associated metadata. Harmonisation is a process where diverse data sources are converted to a single universal format for a given system. The SENAPS platform at the heart of SIMPaCT currently supports data harmonisation as a core functionality.

[5] This topic was directly raised and discussed by one of the Western Sydney Councils interviewed.

Heterogenous data refers to two or more data sets that relate to the same environmental variable (e.g. soil moisture) but have fundamental differences, meaning that they cannot be directly compared without a degree of complex modelling, referred to as heterogenous data synthesis. This modelling goes beyond standard data harmonisation and may be complex, due to fundamental differences between data sources (e.g. differences in data quality; sensor design; sampling rate; reporting interval; and upstream data correction and abstraction). If SIMPaCT grows to be a single large aggregation model it will need to have strong heterogenous data synthesis capabilities, likely well beyond what has currently been developed.

4.3.1.11 Crossing the chasm

A business term relating to technology adoption, 'crossing the chasm' refers to the period between early proof of concept and viable scale, during which a technology is not able to provide a return on investment. In order to 'cross the chasm', the technology requires external support, and is a net drain on resources. Once across, it hits a viable level of maturity and becomes self-perpetuating, often experiencing rapid growth. Most new technologies see chasm periods of at least several years and we believe that SIMPaCT (which is currently at proof-of-concept stage, with limited operational testing or commercial hardening) will see a similar growth trajectory.

SIMPaCT 1.0 at Bicentennial Park is a demonstration of a fully integrated operational instantiation of SIMPaCT. It has been an enormous and significant success that should rightly be celebrated. However, there are aspects of the current system that are known weaknesses, such as its inability to model soil moisture data for 'missing' sensing devices, resulting in sub-optimal irrigation control for large areas of the park. A sophisticated and genuinely innovative approach to the challenge of data intermittency has been established through the pilot project, but the technology team is quite clear about its current limitations and several obvious improvements have been discussed. Once the system runs across a hot summer, many more insights and recommendations for further development of functionality will no doubt emerge. These functionalities will become a focus for a second round of pilot projects and should be assessed and pursued relative to a deepening understanding of various end user needs. Through iterative development in new contexts, SIMPaCT will mature move towards more hardened commercial viability.

4.4 Strategies for achieving the scalability vision

Building upon insights from the SIMPaCT pilot project, the scalability enquiry, the known attributes of the SIMPaCT Solution, and the challenges and opportunities for scalability, a series of strategic approaches can be recommended, to support the high-level vision for SIMPaCT's future.

4.4.1.1 Pursue a mixed funding model for ongoing development and maturation of the SIMPaCT Solution

If it appeared that SIMPaCT had a single simple commercial application with a strong chance of standalone success, a purely commercial investment model could in theory be pursued. This statement does not preclude commercial success; however, regardless of whether commercial success is achievable, it is clear that SIMPaCT exists within the public realm, with a significant existing public investment and a strong potential for public value creation. In any crossing the chasm scenario (see challenges, above), it is generally necessary to engage *all* possible investment sources that align with the value proposition, with not part of the value proposition left unexplored. As such, a mix of funding resources will likely be required, that would include private sector, public sector and research sector investment.

Overview of probable funding options:

- Private investment: Further private sector investment from existing core industry partners will be necessary as SIMPaCT is developed and refined in new contexts over the coming years. For the most part, it is anticipated that this will be in the form of in-kind support as part of an ongoing collaborative effort by invested parties. This might include direct labour, waived licensing fees, and 'at cost' service delivery.
- NSW state government investment: Public sector investment from the NSW state government is likely to be critical, particularly if a strong state government leadership strategy is pursued. Indeed, outside of a grant program that targets digital innovation (e.g. similar to the original funding for the pilot project), it seems likely that state government investment would be predicated on the prioritisation of a public good agenda (e.g. regional water security; western Sydney UGI expansion; metro-scale water and energy demand management) that directly aligns with priority policy commitments. The SIMPaCT value proposition is capable of delivering on such priority policy commitments.
- Water utility investment: Investment from Sydney Water (and potentially other large-scale water utilities). The Sydney Water position clearly identifies the four core SIMPaCT value propositions as critical strategic areas for investment this decade. The possibility of metro-scale data aggregation and smart system control, for advanced value creation around demand modelling and management, builds a stronger case for investment.
- Infrastructure grants: Local governments that invest in irrigation infrastructure do so almost universally through the infrastructure upgrade grants (which may be from state or commonwealth governments). Given the current lack of widespread irrigation infrastructure, the rapid expansion of urban green space, climate pressures, and growing public demand for accessible, healthy and useable green space, it is reasonable to expect that such grants will be increasingly available over the coming years, and that they can contribute to the ongoing development of SIMPaCT. The way that this is most likely to occur is through SIMPaCT 2.0 and 3.0 place-based projects, where SIMPaCT partners with a local

government authority and integrates an infrastructure upgrade grant with other forms of investment in this list as part of a matched funding scenario.

- University investment and funding access: Universities played an important role in the development of the SIMPaCT Solution and made significant in-kind contributions as part of the pilot project. Any potential future government funding may need to be met with further in-kind support of this nature. It is clear that the research associated with SIMPaCT is far from complete, with ongoing opportunities for multi-disciplinary engagements, to develop the technical functionality, interoperability, methodology, environmental science, social science, business models and operational workflows that relate to and support SIMPaCT. In addition to in-kind support, universities can access research funding via more formal funding bodies (e.g. via the Australian Research Council) and less formal trusts and associations, all of which may be reasonably brought to bear in the development and maturation of SIMPaCT over the coming years.

4.4.1.2 Assume that there is a minimum land area size where there is a viable and sustainable business case for a standalone instance of SIMPaCT

There is interest from place owners in what SIMPaCT may be able to deliver at all scales, from very large parklands and precincts, down to small distributed urban parks, streets, sports facilities and schools. Future standalone instances of the SIMPaCT digital twin will require place owners to have a minimum scale of land at which the costs of establishing and operating the system are outweighed by the benefits created.

Further assessment is needed to determine what this minimum scale of land is; however, we can assume that it relates to minimum establishment and operations costs that do not reduce past a lower threshold (See Appendix C). The minimum cost estimates are based on a scenario with just one soil moisture sensing device and one weather station, deployed at a small site with very little complexity. Additional devices and site size can be catered for at relatively little additional cost.

Regardless of what the minimal scale for a standalone instance of SIMPaCT turns out to be, it seems likely that a large amount of green infrastructure will be smaller and thus not a viable application context for SIMPaCT.

For these locations, the only way to deliver SIMPaCT may be through a multi-site digital twin with a subscription model (see Scenarios 4 and 5 in Chapter 5).

4.4.1.3 Increase commercial competitiveness by leveraging unique capabilities enabled by public sector support

As long as technology and its capability at the level of any one place is the primary focus, SIMPaCT will always be in direct competition with commercial irrigation system providers. Even if SIMPaCT delivers a particular unique functionality today, current technology improvements indicate that a commercial provider will develop that capability tomorrow. SIMPaCT needs an alternative proposition to flourish. We must therefore ask: What can a publicly owned and backed SIMPaCT solution do, that commercial providers cannot do?

The public sector (water utilities and state government) has three main advantages over commercial irrigation providers:

1. Publicly backed economies of scale. If the SIMPaCT solution were publicly backed then widespread rollout may achieve economies of scale, with cost savings for end users that increase the value proposition relative to commercial alternatives, improving the competitiveness and viability of SIMPaCT. Public sector backing would require the SIMPaCT IP to remain in the public domain (a current strength) and a clear high-level strategic return on investment for the government that is not achievable by simply relying on market forces. Such ROI is achievable through points 2 and 3 below.
2. The power of big data modelling A centrally managed data aggregation strategy can support the ability to model irrigation requirements using big data, at the scale of entire catchments and regions. This may enable improved management and optimisation of each individual irrigation system and reduce reliance upon on-the-ground sensors.

   If, for example, a Rainbird system models soil moisture using data from its own local sensors and the BOM, then a higher degree of accuracy might be achieved, together with longer-term accurate forecasting, with SIMPaCT augmentation. It may be possible to build business relationships with commercial providers, where a SIMPaCT integration is incorporated into their product delivery as a premium option. The commercial provider could pay a subscription to SIMPaCT and then charge their clients (at profit) for the premium service.
3. The ability to pursue utility-scale management for water and energy demand, bringing powerful value into the proposition that could not be delivered by the private sector.
   a. Demand modelling can support efficiencies in reservoir pumping
   b. Direct management of irrigation scheduling at a metro-scale can reduce peak demand
   c. Direct management of water supply switching at individual locations can reduce peak demand, and support flood buffering

> There is a precedent for commercial engagement with this concept in the energy sector. Remote control of electrical devices by energy utilities, for the purpose of energy demand management, suggests that positive relationships of this nature are achievable.
>
> Major differences between the energy and water sectors may include consumer motivations or incentives to participate. One possibility may be to offer exemptions from water restrictions during drought. Thus, the most likely mechanism would be some sort of special dispensation to irrigators that integrate SIMPaCT (and allow remote demand management by the utility), allowing them to increase total water usage while restrictions are in place.

This kind of additional value creation, that is arguably only achievable through public sector leadership, could drive per-user costs below those of a purely commercial scenario. It is a complex space and more research and direct engagement with irrigation providers is needed to formulate an effective strategy.

4.4.1.4 Avoid a business case based upon marginal returns

To justify operational expenditure and support a business case leading to widespread uptake and rapid growth, it needs to have a clear return on investment. This ROI can be simple and relatively marginal in constrained contexts, where a solution does not experience much variation in how it is applied, or in the benefits sought. However, as soon as solution needs to be more flexible and adaptable, with a broader range of potential benefits to choose from, there is far less room for error. A more general solution, that is capable of delivering a wide range of measurable benefits across a wide range of contexts, must have far larger margins on its prospective returns. We should assume that this rule applies to SIMPaCT.

4.4.1.5 Shift away from reliance on large networks of installed sensing devices at the local scale

Large numbers of installed sensing devices are costly, for capital expenditure for the devices, and for installation, integration and ongoing operation. It also comes with a relatively high degree of risk. Large device networks take time to set up; usually considerably more than anticipated. Challenges arise with faults, installation issues, communication issues, and data quality concerns, adding more time and expense. For SIMPaCT, these costs and risks can be reduced substantially by reducing reliance upon large numbers of installed sensing devices.

The SIMPaCT pilot in Bicentennial Park saw the installation of over 200 soil moisture sensors. A very high attrition rate led to a final functional network of less than half this number. SIMPaCT has been proven to operate with this smaller number of devices, however it is likely that desired outcomes can be achieved using even fewer devices, particularly if additional advanced modelling capabilities can be developed to interpolate missing sensor data within an operational area. The aim for future sites is to run SIMPaCT reliably, using a fraction of the number of sensing devices used for the pilot project. Future development of SIMPaCT should pursue this as a priority.

4.4.1.6 Shift system establishment and sensing to commercial irrigation providers

SIMPaCT may ultimately seek to focus on delivery of a data service. A major component of the cost of SIMPaCT is in establishing a new system. The pilot project in Bicentennial Park was exploratory, and thus the setup was far from streamlined. However, even discounting for this inefficiency, the pilot illustrates how manual and complex system establishment can be. Multiple site visits for planning and approvals; a prolonged process for establishing a local communications network; custom device mounting infrastructure designed specifically for that park; multiple site visits for installation and many more for troubleshooting; many hours of desk-based troubleshooting and verification; many more hours managing devices and their integration with the SIMPaCT digital twin; and extensive work documenting device deployments and metadata.

All of this work can in principle be outsourced to commercial irrigation providers. If this is the longer-term goal or 'end-game', then SIMPaCT can aim to be a self-contained digital service. Ultimately, no SIMPaCT team member should need to set foot on a site or ever have to deal with sensing devices. There should be data in and data out, all via an integration with a smart irrigation system. Such an approach is the key to true scalability, dramatically reducing the cost, time and complexity of establishing SIMPaCT at new sites. To be clear, this is likely not achievable in the short term; there will need to be more place-based iterations of SIMPaCT in the interim that are somewhat similar in complexity and hands-on effort to the first pilot project (see SIMPaCT 2.0 projects in Chapter 6).

This strategic approach is achievable considering that SIMPaCT requires a smart irrigation system to be in place already, and most smart irrigation systems include their own sensor networks (soil moisture, weather station, etc.). It is expected that all will do so soon, as low-cost sensor technology rapidly matures in the coming years.

5 SCENARIOS FOR A FUTURE SIMPACT

Having established the criteria for success and strategies for achieving scalability which draws on the background research, the project has identified five scenarios for scaling SIMPaCT at different levels of commercialisation and targeting different possible users and scales. The scenarios have varying potential to support the high-level vision and align with high-level strategies.

These scenarios plot the range of opportunities for SIMPaCT, with a description of their potential for long term impact, and their benefits and risks.

5.1 Scenario 1: Commercial package, stand-alone place-based installations

Under this scenario, the focus would be on the commercial maturation of the SIMPaCT pilot solution, which would be replicated to deliver equivalent smart irrigation services to new customers in new locations.

Further testing would be required to understand the degree of customisation that may be required for each new location, proposed in the Pathway as 'SIMPaCT 2.0' implementations (see Chapter 6). This testing will determine the duration of future involvement of the SIMPaCT research team before SIMPaCT can be offered on a commercial basis. SIMPaCT 2.0 is also required to test the cost for a new instance of the SIMPaCT digital twin, given the potential complexities inherent in assessing a new location, designing the installation scope and details, as well as the hosting and staffing implications. These costs will be incurred even if there is little customisation required for the central platform. If a simple 'cut and paste' model can be shown to work without customisation, this scenario has the potential for widespread uptake, leading to the benefits offered by SIMPaCT being more widespread. If it does not require project team support, it may be viable for implementation interstate and internationally

The risks for this scenario are that SIMPaCT's cost as a stand-alone product will be too high for most place owners, especially those in the public sector for whom basic commercial irrigation systems are already precluded by cost. It will be competing with commercial systems that offer enough similar functions to outweigh any value. As such, it may only be viable for a few years until the market catches up and then only for a few less cost-sensitive user groups.

Opportunities: development precincts; multiple park grouping; prestigious buildings, homes or sites; golf courses; large outdoor sports facilities; defence grounds; locations with highly valuable plants.

5.2 Scenario 2: Creative Commons

There is the potential to expand SIMPaCT's reach and scope by making the solution open source under a creative commons licence, allowing others to implement or grow it themselves. Standalone or grouped place-based installations are possible; or (depending on the nature of the creative commons licence) commercial irrigation system providers may use SIMPaCT to improve their own product offerings. Other research teams may wish to build on the SIMPaCT solution under this scenario, which suggests the possibility of new functionality and applications.

If SIMPaCT is modified by others to suit their own needs no support from the SIMPaCT project team would be expected.

The creative commons scenario presents the possibility of establishing a Community of Practice, probably with other research projects or institutions. They may have innovative ideas to build on SIMPaCT, or are in locations distant from easy support from the project team and therefore extend SIMPaCT's geographic reach. Some involvement from the SIMPaCT team is possible in this case.

This scenario has similar benefits and risks to scenario 1.

5.3 Scenario 3: Licencing

Use of the SIMPaCT solution could be licensed to one or many commercial irrigation system providers. Care would be needed in developing the licence conditions to ensure that the purpose of SIMPaCT is clearly defined and understood, and that it is marketed, installed and maintained in a way that does not detract from SIMPaCT's reputation. There is a risk that a commercial provider may not wish to share the SIMPaCT advantage with others, so would require exclusive rights, limiting SIMPaCT's reach. Alternatively, they may not wish to be constrained by licence conditions and therefore use knowledge of the solution to develop their own competing product.

Licensing also provides a mechanism to broaden the geographic reach of SIMPaCT such as through working with universities or agencies interstate or internationally to implement it in their own region. In this case, implementation may take the approach of stand alone as per Scenario 1, or aggregated as per Scenarios 4 or 5.

The main benefits of this approach are that it enables wider distribution without much direct involvement of the initial team, and that licencing fees may help to fund development work on SIMPaCT.

5.4 Scenario 4: Subscription model

This scenario is for a district scale digital twin that offers SIMPaCT services on a subscription basis. The concept was devised in anticipation that the cost of a stand-alone SIMPaCT solution will be found to be too high for most place owners. The idea is to share the cost of buy-in to SIMPaCT by establishing a shared service that enables access for smaller-scale landowners.

A technology provider would establish a single centralised digital twin, into which any standalone smart or semi-smart irrigation systems (with appropriate baseline interoperability) within the district may be integrated. This solution would be developed to cater for scale, servicing multiple commercial systems, sites, and clients at once. Data shared with SIMPaCT would include whatever soil moisture and local meteorological data is made available from a given irrigation management system, plus operational data for that system (e.g. flow rate, etc.). A park profile (fixed system data - metadata about the location, stations, and design of the system) would also need inputting during the setup of a new site integration. The central SIMPaCT digital twin would perform modelling and forecasting and issue commands back to the multiple irrigation systems, optimising their operation.

Further work is required to determine the effort, time and cost that would be entailed in expanding the SIMPACT pilot platform for this application. Also relevant to its feasibility will be SIMPaCT 2.0 testing, on what inputs would be needed for each new location, and therefore the complexity of adding each new subscriber.

As well as facilitating a wider distribution and sharing of SIMPaCT's benefits, the data aggregation that this makes possible may allow coordinated management of water consumption across the region.

This scenario could be privately run on a commercial basis, possibly under a licencing arrangement, with similar risks to those from licensing to an irrigation system provider. Its main benefits are that it allows smaller scale UGI owners such as local governments or golf/sport clubs to afford SIMPaCT services, and it can achieve wider distribution without needing team involvement.

5.5 Scenario 5: Public good

Taking scenario 4 further, an exciting possible future pathway for SIMPaCT is the establishment of a publicly owned and managed metropolitan-scale smart irrigation digital twin that delivers affordable and accessible services to place owners while also establishing powerful new water management capabilities for the water utility. From the project commencement, a key focus of the funder was to assist other government agencies and water utility providers in transitioning to smart irrigation management, which this scenario delivers.

In the case of metropolitan Sydney, Sydney Water (or DPE Water) would establish a single central SIMPaCT digital twin. The benefit to irrigators is that a low-cost subscription model with an annual fee dramatically reduces the per-user cost. Connection could even be free, where the 'cost' to an irrigator is an agreement to hand a degree of autonomy over its irrigation systems to Sydney Water, in exchange for the benefits that SIMPaCT delivers.

In addition to the standard SIMPaCT functionality and benefits, two additional outcomes may be sought:

a. Catchment and regional-scale modelling that improves the optimisation of individual irrigation systems at the local scale

Largescale public data aggregation represents a new form of value creation that is not accessible to the commercial sector. Such big data has the potential to support catchment and regional-scale modelling of soil moisture relative to larger-scale weather and climate trends. If such modelling can be used to improve the performance of the SIMPaCT digital twin when operating at a catchment scale, it has the potential to improve the optimisation of individual irrigation systems at the local scale.

An additional benefit may be the ability to reduce the reliance upon on-the-ground IoT sensors. Where the SIMPaCT pilot project used 200 soil moisture devices, a future site of comparable size, connected to a metropolitan-scale model with big data modelling (and more advanced analytics capabilities), might operate effectively with many fewer sensors. Indeed, as such a system achieves scale it may be unnecessary for certain kinds of new site to have any sensors at all.

b. Utility-scale demand management for irrigation water

The primary benefit for Sydney Water of a metropolitan-scale SIMPaCT digital twin is the capacity for metropolitan-scale water management, and the management of peak water demand associated with irrigation. Potential cost savings could be enormous and, in theory, justify the significant initial investment required to develop and operate such a system, which may be required over several years before returns are likely to be seen. Following is an in-principal articulation of the value to water utilities, based upon consultation with Sydney Water. The Roadmap recommends a Sydney Water internal research process, investigating the underpinning assumptions, culminating in a position paper.

A precedent for utility-scale peak demand management has already been set by energy utilities. Water peak demand management can be achieved because:

- A window for watering occurs prior to a known upcoming heat event. A utility can stagger delivery across multiple sites, avoiding scenarios where all sites water simultaneously, which smooths demand peaks.

- Pre-watering of soil aids in the future infiltration of water and slow irrigation over a longer period may be more effective at maintaining optimal soil moisture than short-period deluge, so water demand can be spread over longer periods.
- Optimising water delivery across multiple sites avoids over-watering around peak irrigation events.

Management of peak demand helps in the following ways:

- It avoids expensive water supply that is used to service peak demand (e.g. desalination water, recycled water)
- The need for pre-pumping of water in reservoirs, to meet demand, can be more effectively managed, and potentially reduced. Together with not having to treat as much water during heat waves when energy costs are high, this may have enormous energy cost savings, as well as carbon emission savings.
- Given that pumping of water for irrigation contributes to peak energy demand on hot days (when air conditioning use is also high), there are potential outcomes for reducing energy peaks that benefit electricity utilities.

This vision has been developed in collaboration with Sydney Water, from interviews with multiple Sydney Water staff, and has been reviewed and supported by the project Sydney Water representative, with the focus on metropolitan Sydney. However, the scenario could easily be applied to other locations and water utilities, including in regional settings, tying in to state and federal government water management policies. SIMPaCT could be owned and managed by DPE Water, with coalitions of smaller local water authorities coordinating water management in their own regions.

Scenario 5 is based around a core concept of big data aggregation, and the value that this can unlock. This is an emerging trend in IoT and smart cities that can be expected across multiple sectors in the coming years. Examples of big data aggregation are already evident in NSW, from air quality monitoring to defibrillator data and the approach is expected to dominate later this decade, with major public sector leadership. Aligning the maturing of SIMPaCT with this trend reinforces its future focus.

6 SCALABILITY PATHWAYS

6.1 The Pathway

The SIMPaCT Roadmap has defined six phases for scaling SIMPaCT. The implementation pathway accommodates making a start on all scenarios in the first three phases, deferring determination of one favoured scenario until further insights emerge from SIMPaCT 2.0 place-based project (Phase 3). These insights should relate to:

- The ease or difficulty of maturing the SIMPaCT solution in its current form
- The degree of additional development and customisation required to adapt the solution to new contexts
- The cost of delivery relative to various new contexts and key factors
- The business case for establishing and maintaining the solution in new contexts

Following phase 3, divergence may occur based upon insights and market conditions. It is possible that all scenarios continue to develop in parallel, or that certain ones emerge as more promising.

6.1.1 Six phases to maturation

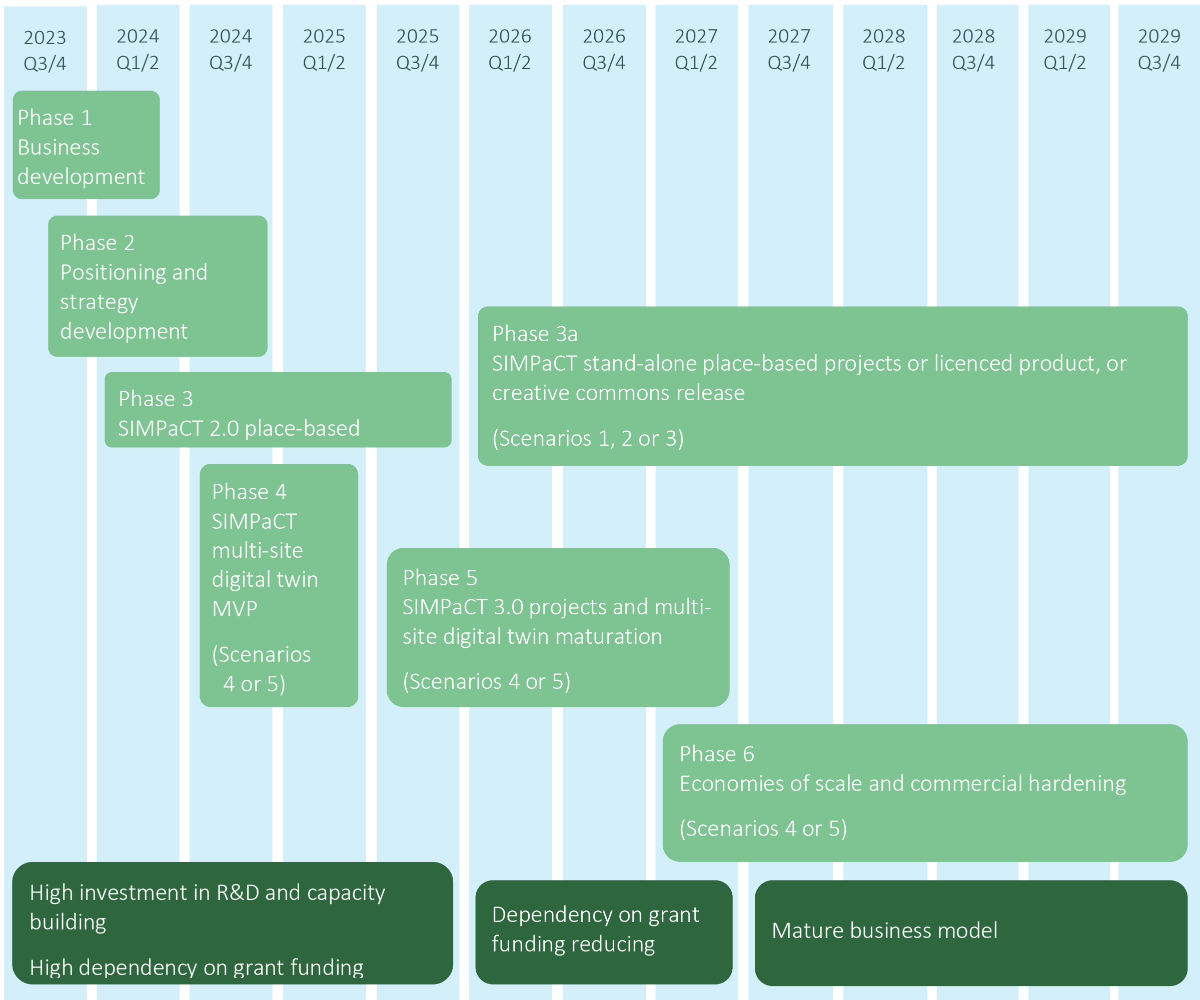


Figure 5. An overview of the six phases of the SIMPaCT scalability pathway

6.1.2 The six phases in detail

6.1.2.1 Phase 1: Business development (late 2023 to early 2024)

A period of time spent leveraging the initial success of the SIMPaCT pilot to flesh out new proposals and secure new funding. Critical areas include:

- Within SOPA
  - Negotiating the additional 6-12 months of staffing support for the Bicentennial Park system, which is being externally funded. The purpose is to ensure that a full summer of data can be collected and analysed, with the aim of proving the functionality of SIMPaCT (note: this work began in May 2023, prior to pilot project completion and may be complete by Q3-2023).
- Within Sydney Water
  - Secure support for the development of a position paper relating to the future of smart irrigation for Greater Sydney.
- Core partners (WSU, Sydney Water, DPE, Eratos, UTS)
  - Agreement on legal responsibility, processes for pursuing and selecting new project opportunities, and on ownership and use of IP, especially in a commercial arrangement.
  - Developing and securing funding for new place-based projects (SIMPaCT 2.0 projects). Likely to have a strong focus around priority locations for Sydney Water.
- Academic research (optional, if opportunities are apparent) (UTS, WSU)
  - Focus should be on accessing research funding that can further the SIMPaCT agenda and which would not otherwise be accessible.
- Secure funding for data analysis and a report on 'One year of SIMPaCT operation (2023-2024) in Bicentennial Park'.
  - This assumes the system is sustained for at least 12 months, capturing data over the summer of 2023/24.
  - Funding sources may include research funding, and/or combinations of support from the NSW government or Sydney Water.
- Secure funding for a policy and standards review (NSW)
  - The review should aim to understand the existing standards and policy landscape that relates to a long term vision for SIMPaCT.
  - Aim of the review is to strategically leverage a long term vision for SIMPaCT and smart irrigation in NSW and/or nationally by understanding and engaging with policy and standards.
- Secure support for a roundtable in Q1/2 2024 on 'The future of civic irrigation'
  - Assume partial support from Sydney Water
  - Approach LGNSW
  - Approach Committee for Sydney
  - Approach water associations
  - Approach NSSN and IoTAA

Note: Business development will continue into subsequent phases, but is the main focus of phase 1

6.1.2.2 Phase 2: Positioning and strategy development (Late 2023 to end 2024)

A phase focused on gathering evidence, positioning key partners, confirming value propositions and further developing a longer-term strategy. Critical deliveries in this phase include:

- SIMPaCT 1.0 Impact Report
  - Based on 12 months of data from the Bicentennial Park SIMPaCT digital twin, including the summer of 2023/24 (which will probably be an El Nino year requiring irrigation).
  - The report will provide evidence of SIMPaCT's functionality and is expected to support claims made at the close of the pilot project regarding its value proposition.
- Sydney Water position paper on the future of smart irrigation for Greater Sydney
  - Following a process of internal research that explores and tests the ideas and vision for a metropolitan-scale smart irrigation digital twin, as outlined in the SIMPaCT Roadmap.
  - Focus should remain on *civic* irrigation, though agricultural sector applications may be considered if Sydney Water feels that these need to be included.
  - Should contain detailed modelling of water demand management, water-energy relationship, etc., to prove (or disprove) claims of value creation made in the Roadmap.
  - Should present a business case for Sydney Water commitment to a long-term vision for smart irrigation. Assuming this aligns with the SIMPaCT Roadmap, this report positions Sydney Water as a committed leader of that vision.
- 'The future of civic irrigation' roundtable and report
  - Bring together all potential stakeholders in NSW and beyond

    - The purpose is to establish a new community of practice and kickstart a broader process that culminates in a white paper on smart irrigation.
- White Paper on smart irrigation
    - To be written and presented as the joint effort of a coalition of concerned organisations, that will likely include:
        - Sydney Water
        - NSW DPE
        - Universities (including but not limited to WSU and UTS)
        - LGNSW
        - Sydney-based organisations (GCC, CfS, etc.)
        - Water organisations/associations
        - Industry associations (e.g., IoT Alliance of Australia)
    - The purpose of the white paper is to establish a clearly articulated public sector agenda for smart irrigation, in recognition that:
        - irrigation is becoming smart with or without public sector leadership
        - commercial irrigation providers cannot be expected to ensure that public interests are prioritised
        - enormous public value can be gained if decisive public sector leadership is taken, in areas of climate resilience, resource management, carbon emission reduction, public health, etc.
    - To focus primarily on civic irrigation (unless the Sydney Water position paper chose to expand to cover agriculture).
    - The white paper will provide a much-needed foundation for establishing public sector leadership on the topic of smart irrigation and should cement strategic partnerships and long-term resourcing for the development and maturation of SIMPaCT.
    - The white paper will draw upon a number of preceding elements to support its position, including:
        - The SIMPaCT 1.0 impact report
        - The Sydney Water position paper
        - A policy and standards review (see phase 1 for details)
        - Outcomes from 'The future of civic irrigation' roundtable
        - Further correspondence with coalition partners, as required

6.1.2.3 Phase 3: SIMPaCT 2.0 place-based projects (early 2024 to late 2025)

To achieve the long-term vision for SIMPaCT, a period of second-generation place-based standalone instantiations of SIMPaCT will be required.

SIMPaCT 2.0 projects will they take the solution developed for the pilot project and replicate it at new sites, working with new place owners, new irrigation systems, and new contexts and challenges. These new projects will build upon the success of the SIMPaCT pilot, finding greater efficiency in some areas of project establishment and developing and refining the approach, technical design and methodology. SIMPaCT 2.0 projects will be second phase pilot projects because they will be used to determine how much work is required by the project team to adapt the current demonstration version of the SIMPaCT solution to a new context, the degree of customisation required to adapt a more mature but generic version of SIMPaCT to a new location and irrigation management system, and the inputs each new instance would need. In broadening the range of sites and contexts, this phase can test the complexities and costs created by various changed contextual factors. The findings from the SIMPaCT 2.0 projects will inform the decisions about which scenarios can be taken forward, and the business case for them.

In order to keep all options open, new sites should be chosen with strong alignment to a Sydney Water agenda and strategic focus, and therefore be within Greater Sydney. While there are no doubt opportunities in regional NSW and elsewhere, it is harder to connect these back into a core strategy for achieving a metro-scale smart irrigation digital twin. We therefore suggest that a focus is maintained on Sydney Metro, unless the concept is instead concentrated in a regional location under the auspices of DPE Water.

Because the cost of establishing and operating SIMPaCT in its current form is too high for most individual irrigators, and SIMPaCT 2.0 projects are part of the solution development phase, they are likely to be dependent on grant funding until a strategy to reduce per site costs can be revealed through their pursuit.

Each new project will feature its own standalone instantiation of SIMPaCT. However, once these are established, they will enable the start of Phase 4, the 'SIMPaCT multi-site digital twin MVP'.

6.1.2.4 Phase 3a SIMPaCT stand-alone place-based projects or licenced product, or creative commons release

Subject to the results of SIMPaCT 2.0 projects in Phase 3, SIMPaCT may be ready for a roll-out under one or any of scenarios 1, 2 or 3. Phase 2 will inform which of these scenarios should proceed, and whether this would be the only future for SIMPaCT or if development towards scenarios 4 and 5 should occur in parallel.

6.1.2.5 Phase 4: SIMPaCT multi-site digital twin Minimum Viable Product (mid 2024 to late 2025)

This progresses the metropolitan-scale data aggregation platform of scenarios 4 and 5. This might be applied within a metropolitan context (e.g. by Sydney Water or NSW DPE) or in a regional context (e.g. a block of south western regional LGAs, led by NSW DPE).

The Minimum Viable Product (MVP) is a proof of concept that will demonstrate an instance of the SIMPaCT digital twin working as a single modelling and command system across multiple sites.

Phase 4 is contingent upon:

a) A Sydney Water position paper that commits to its creation (or a DPE position paper if a regional approach is pursued)
b) Establishment of at least two SIMPaCT 2.0 place-based projects in phase 3 (both in Sydney metro, or all in the same region)

Early work on Phase 4 may proceed immediately after publication of the Sydney Water/DPE position paper. This might include planning for the technical design of the MVP and establishment of roles, responsibilities, resources, administration etc.

The MVP will initially be created as a standalone instantiation of the existing SIMPaCT digital twin, featuring multiple connector applications within the Irrigation adapter module, allowing integration with irrigation systems across multiple sites (ideally three or more).

Each irrigation system will send its data in parallel to its own standalone instantiation of SIMPaCT and to the MVP. The MVP will then attempt to do the job of all the standalone systems at once, producing command outputs for each system. These outputs would not need to be connected to the irrigation systems unless a test was made; the main aim would be to test a central system and its ability to produce real time commands. Performance of the MVP could be directly compared to the performance of each standalone instantiation.

In theory, the MVP should require minimum development, however it may need to address challenges of interoperability, data harmonisation and heterogenous data synthesis. It should begin soon after SIMPaCT 2.0 projects are established and will likely require development and testing throughout those project periods.

6.1.2.6 Phase 5: SIMPaCT 3.0 projects and multi-site digital twin maturation (Mid 2025 to mid 2027)

SIMPaCT 3.0 projects are envisioned as new place-based projects that use only the Smart Irrigation Digital Twin from day one. Unlike SIMPaCT 2.0 projects, they would not have their own stand-alone instantiations of the SIMPaCT platform.

The aim would be to:

- Test the model for establishing new site integrations with SIMPaCT, where a majority of sensing and site operations is outsourced to the irrigator and the irrigation provider
- Diversify the number of irrigation system integrations that are possible, working actively with commercial providers on interoperability outcomes and mutually beneficial commercial agreements.
- Diversify the variety of sites (size, type, water requirements, etc.) to test the flexibility of the system.
- Develop and harden the commercial model for a subscription-based data service
- Develop more advanced data analytics (geospatial modelling and Machine Learning) that can make use of larger data sets from multiple sites, to provide improved model outputs for optimised operations at individual sites.
- Develop demand management capabilities as a major new functionality within SIMPaCT, and test these with select sites. Note that until full scale is reached (Phase 6), it will only be possible to test the technical capability of demand management.

6.1.2.7 Phase 6: Economies of scale and commercial hardening (2027 onwards[6])

Phase 6 is where economies of scale begin to emerge, with many sites connected across Sydney or the regional area. This is where:

- Large quantities of data from all sites can be shown to directly benefit the optimisation of individual site operations
- A significant number of sites are connected to a demand management function, such that real measurable demand management benefits become apparent for Sydney Water or the coalition of water utilities.

[6] Note that phase 6 (and potentially phase 5) have less clear timelines and may begin earlier or later than stated, depending on funding, capability, the level of technical challenges encountered, and other hurdles.

- An affordable subscription rate for SIMPaCT customers can be supported by economies of scale (i.e. critical scale for a viable self-sustaining business model is achieved).

By Phase 6, SIMPaCT should be rapidly emerging as a ubiquitous central element in Sydney's (or regional NSW's) irrigation landscape. It should also be garnering significant international attention and acclaim. A dedicated marketing and communications workstream should have been established to leverage this.

6.1.3 Prioritising geographies

Discussion is needed on how to prioritise future site opportunities in order to concentrate attention, time and resources that are best aligned the establishment of the strategic pathways discussed here.

From Phase 5 onwards, it is reasonable to expand the geographic reach of SIMPaCT beyond its initial region.

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APPENDICES

A CONSULTATIONS

Engagement methodology

The research included stakeholder interviews with the aim of developing an understanding of who potential future users of SIMPaCT may be, and their needs and limitations, and the current status of irrigation in their jurisdiction. Recommendations from members of SIMPaCT scalability working group contributed to the selection of stakeholders for the interviews. Interviewed stakeholders were primarily local governments, both regional and metropolitan because very few other large scale parks and gardens irrigators could be identified. The focus was on current and future water management strategies adopted by the local governments along with any additional automation undertaken to optimise irrigation. One of the aims was also to understand the motivations and impediments that would drive conditions for a future SIMPaCT. Although some discussions touched upon smart city initiatives (ongoing and future), this was not considered a priority.

The interviews were conducted as online semi structured interviews and were undertaken either as one-on-one or in groups interviews depending on the availability of relevant personnel. In total, 9 one-on-one interviews and 5 group interviews were conducted

Selected members from the SIMPaCT project team were also interviewed on questions relevant to their role in the project, to ensure their experience and expertise is reflected in the analysis and recommendations.

Interview duration ranged between one and one and a half hours depending on availability. The challenge of limited time availability meant the discussions were kept focused and targeted to water management and irrigation status. Other guiding factors that helped prioritise questions were availability of personnel in the proposed timeframe, their roles, and their backgrounds or expertise.

Ethics approval was obtained from the University of Technology Sydney, Human Research Ethics Committee through the ISF Responsible Academic. The project information provided to participants in advance of the interviews included information about Ethics and how their responses may be used. Consent was obtained verbally.

Participant recruitment

Because the intention of the interviews was to find potential future users of SIMPaCT, the personnel who were requested to participate related to water management, green infrastructure management, sustainability and resilience roles. The roles that participated ranged across various departments including strategic planning, open spaces, park maintenance or park facilities team, city services and water management, sustainability and resilience.

Participants were contacted by email, outlining the objective of the interview and providing information on the project. Interview questions and project information was shared as a pre reading for all participants before the interview.

Interviews and conversions were undertaken with representatives from the following organisations.

Organisations	Number of people interviewed	interview subject, or Expertise or role of interviewee
Western Sydney University (1:1 interview)	1	Professor of Planning Director, Urban Transformations Research Centre
ERATOS (group interview)	2	CEO Chief Customer Officer
HARC (1:1 interview)	1	Senior integrated urban water modelling and data engineer
Sydney Water interviews		
Interview 1 (1:1)	1	Service planning lead
Interview 2 (1:1)	1	Developer responsibilities
Interview 3 (group interview)	7	Planning and strategic planning team, smart cities team, regional planning
CentraTech Services	1	Operations Manager

Organisations	Number of people interviewed	interview subject, or Expertise or role of interviewee
Water Conservancy (1:1 interview)	1	Senior member
Orange Council (1:1 interview)	1	City representation space; water and parks team
Warren Shire Council (1:1 interview)	1	City services; water team
Liverpool Council (1:1 interview)	1	Open spaces and overall water management; smart metering
Blacktown Council (group interview)	2	Environmental initiatives
Paramatta Council (brief discussion)	1	Smart cities initiatives; smart water management
Penrith City Council (group interview)	5	Sustainability and resilience initiatives at the city level, operations and maintenance of the parks and sports fields
Inner West Council (group interview)	4	City level sustainability initiatives, park and open spaces management; strategic planning

Data collection and analysis

Interviews were video recorded and handwritten notes taken for reference purposes only. Information collected through the discussions were collated thematically. In situations where information was not clear or needed further investigation, participants were contacted again via email requesting responses to short but focused questions.

Questions for participants

A comprehensive list of questions was prepared and shared with the participants ahead of the meeting by email or as an attachment to the interview invitation. The questions were used to trigger discussions not to provide a rigid structure. The discussions ranged across topics depending on the roles of people attending and their background or expertise or knowledge in the field of water management. The number of participants affected the time available to explore some topics in depth.

Local Governments

1. What irrigation assets (if any) do you own/operate?
    a. Discreet locations
    b. Land area
    c. Types of asset (e.g. playing fields, gardens, trees, turf, etc.)
    d. What is the source of water for irrigation- potable or recycled and why?
    e. Current irrigation system functionality? Do you use any smart technology?
        i. Do you have smart meters? Where are they located and reason for their location
        ii. Total number of irrigation systems in use?
        iii. Operations? Council-managed, or contractors?
    f. What are your current pain points/challenges?
2. Do you have significant new developments where irrigation is being considered, or is already approved?
3. Do you use (or have the capacity to use) recycled water?
4. Do you have your own water efficiency or water management plan in place? If not, are there any discussions about preparing one in the near future?
5. Do you have any other policies around water management, water efficiency etc?
6. Please comment on Council's relative concern about the following pressures/challenges
    a. Urban heat
    b. Water scarcity
    c. Cost of water supply
7. Please comment on the relative importance to Council of achieving the following outcomes
    a. Cool places/suburbs/parks

   b. Healthy and well-managed parks/trees/green infrastructure
8. Do you have an existing program/team/strategy for smart city/innovation?
9. What is your capacity for taking on new projects (e.g. a smart irrigation project)? What will be the criteria for assessing the feasibility? Considerations:
   a. funding availability
   b. demand on your resources/time/staff
   c. outcomes
      i. financial
      ii. social
      iii. environmental

SIMPaCT project partners and others

Sydney Water (1:1 and Workshop)

1. Data aggregation
   a. How can Sydney Water assist here?
2. Sydney Water's view on the idea of an opensource data and subscription based service. Eratos hosting the platform where IP owners can continue getting their share
3. Value proposition
   a. What is the value proposition for Sydney Water through SIMPaCT?
   b. How can SIMPaCT solve issues that Sydney Water is currently facing in the metro region?
   c. Based on your experience, what is the value proposition for local governments? From our discussion with Councils, operational issues around irrigating Council owned sports fields is the no.1 concern for them
4. Relationship between precinct and developers and how can SIMPaCT be used?
5. What do you think about the use of recycled water for passive irrigation on street trees (Sydney Water and Western Sydney Council partnership projects)
6. Can SIMPaCT be used at the design stage or be used as a planning tool to help design better irrigation systems?

Eratos (Group interview)

1. What is the value that SIMPaCT can bring to your organisation?
2. What do you think the value proposition of SIMPaCT is for:
   a. Metro councils and precinct authorities
   b. Regional councils
   c. Water utilities
3. How do you imagine an ongoing commercial arrangement might work between Eratos, HARC and the use of the WSU Machine Learning (ML) component?
4. Do you anticipate ethical or privacy concerns relating to the accumulation and sharing of data, particularly if we scale around a growing ML capacity that draws data from multiple projects. How would we manage this?
5. How do you see future commercial licensing options working, given the stipulation that the project IP must remain in the public domain? Would Eratos open source project code? What would that even mean?

HARC (1:1 interview)

1. Do you anticipate prospects for future economies of scale and what might these be?
2. What is the value proposition for HARC as an organisation
3. Views on developing a lean model vs optimal model of SIMPaCT.
   a. How can the application of the current model be more lean and is able to adapt to drought situations, where water needs to be carefully managed and is not provided if not required.
   b. Has the leanness of the model been tested?
4. How can the model be developed for wide range of users and how adaptable or agile can the model be? What would be the challenges from HARC's perspective?
5. How can the model be used as a planning tool to determine water allocation and management policies for local governments, where budgets are tight
6. What do you think are the challenges in scaling the model?
7. Any comments on IP?

Water Conservancy (1:1 interview)

1. What is your experience around working with metro as well as regional Councils of the following aspects;
   a. Water efficiency and water management in general
   b. Public amenities
   c. Irrigation and systems
2. What are the key challenges for local governments around water management, specifically irrigation?
3. What is your view on the policy landscape urban resilience and climate change, and do you think existence of these policies can influence the water management policies especially?
4. Do you think a solution like SIMPaCT can add value?

Western Sydney University (1:1 interview)

1. What is the value that SIMPaCT can bring to your organisation and what contribution might your organisation have in the future scalability of SIMPaCT?
2. What could be the possible internal limitations or barriers within the organisation?
3. Views on split incentives and how and where should they be considered in the scalability roadmap
4. What site and project governance arrangements are necessary/helpful?
5. Where do responsibilities and risk lie?

Centratech Systems (1:1 interview)

1. What does SIMPaCT do that enhances the functionality of Fieldmouse?
2. In what way does SIMPaCT bring commercial value or service to your clients?
3. What is the value proposition to CTS commercially?

B SMART LOW-COST SENSING DEVICES

Smart

'Smart devices' are devices that are connected to the Internet of Things (IoT). They communicate data wirelessly, in near real-time, enabling large distributed networks, and the utilisation of live data streams. More sophisticated smart devices may have varying levels of onboard processing for data correction and abstraction, as well as smart operational functionality.

Smart devices are generally compared with data loggers and handheld reference equipment.

Low-cost

The term 'low-cost' is broadly used within the IoT and smart cities sector, as well as by state and international organisations concerned with meteorological and air quality monitoring, to describe smart devices that are low in cost compared to more established types of (generally) higher performance equipment that is used to measure the same variables.

The cost estimates that relate to 'low-cost' vary by type of telemetry.

- Low-cost meteorological sensing devices: For meteorological data collection, high-performance sensing equipment will comply with international standards, and will be of a type used by meteorology bureaus. This equipment can cost between several thousand and several tens of thousands of dollars. 'Low-cost' describes meteorological equipment that does not comply with these standards. It can include what may be thought of as 'ultra-low-cost' compact IoT devices (e.g. the temperature and humidity sensing devices used for the SIMPaCT pilot project), which tend to cost between $100 and $1000 per unit (depending on the make and model). The low-cost distinction may blur when we consider mid-performance weather stations that might cost several thousand dollars per system (e.g. the solid state weather stations used for the SIMPaCT pilot project).
- Low-cost soil moisture sensing devices: There is no formal definition of a low-cost soil moisture sensing device. Certain types of component sensors (e.g. the capacitance probe used by the SSM20 Sensedge Soil Moisture Senstick in the SIMPaCT pilot) are broadly referred to as being low-cost (Valera and Luštrek, 2022; Nagahage et al., 2019), making devices that utilise them 'low-cost devices'. Extensive use of both terms in the academic literature occur in reference to IoT and smart wireless sensing networks.

Key challenges with low-cost sensing

Accuracy

'Low-cost' sensors are designed to function differently to higher-cost higher-performance sensors. They tend to use entirely different technologies that measure quite different variables, and these technologies may vary in cost and accuracy[1]. The choice of lower-cost sensing technology tends to involve a trade-off between accuracy and cost. The result is that for a given sensing network, more low-cost sensing devices may be procured and deployed for a fixed budget, resulting in larger amounts of more spatially distributed lower-accuracy data.

The challenge then becomes how to interpret larger less-accurate data sets in useful ways. With the rapid emergence of commercially available low-cost sensor technologies over the past several years (in line with the expansion of smart cities and IoT), the ability to generate such data sets has outpaced the data science needed to extract the maximum possible value from them. There is now a notable effort to improve low-cost sensing technologies and their integration (Briciu-Burghina, 2022; González-Teruel et al., 2019; Nagahage et al., 2019), and to develop new approaches to data interpretation and modelling (Schwamback et al., 2023; Placidi et al., 2021; Valera and Luštrek, 2022), in order to access the value in these data sets and unlock the true potential of low-cost sensor technology.

Reliability

Smart sensing networks that consist of any larger number of low-cost sensing devices, or which require devices to be optimised for battery-only power, rely upon local area networks for wireless communications. This is because alternative communications (commonly LTE and Wi-Fi) have per-device cost scaling challenges, and high power-demand (which precludes battery use). Low Power Wide Area Network (LPWAN) technology comes in several forms (e.g. LoRaWAN, Sigfox, NBIoT) and provides wireless communications for devices within a 'local' area; usually a radius of up to a few kilometres of a gateway (depending on topology, vegetation and built environment, which may block or attenuate signal). Signal coverage across an area covered by an LPWAN can be highly variable, with many radio 'black-spots'. For soil moisture sensing, where devices are at or below ground level, connectivity issues are compounded.

While not universally the case, there is a general trend towards smaller numbers of high-cost high-performance sensing devices utilising high-reliability (and higher cost, higher bandwidth and higher power-demand) communications technologies like LTE, and larger networks of low-cost lower accuracy sensing devices utilising lower-reliability LPWANs. The upshot is that low-cost sensing device networks tend to have reliability issues relating to communications.

In addition to reliability issues relating to communications, low-cost devices may experience outages due to poor design or performance. Device quality is constantly improving, however there are no standards in place for low-cost sensing device performance, meaning that improvement is left to market leadership.

Whether reliability stems from communications challenges or other device performance challenges, the impact on data streams is generally high intermittency, leading to data sets that are effectively 'full of holes'. The challenge then becomes how to make use of data sets with large amounts of missing data. The solution is broadly based around having a large enough data set that missing sections can be inferred through modelling. Such modelling capability is still in its relative infancy. SIMPaCT has demonstrated an approach to this kind of modelling that may be significant across a variety of low-cost sensing applications, beyond just soil moisture sensing.

The value proposition of low-cost sensing

Despite inherent challenges with accuracy and reliability, low-cost sensing has a strong value proposition, as it enables the collection of new types of previously unattainable data sets. The key is affordability, scale and spatial coverage. Due to low device costs, a larger number of devices can be procured for a fixed budget. Devices also tend to be compact, making their deployment relatively low cost compared to bulkier high-performance equipment. As commercially-available low-cost sensing devices have emerged, so too have large distributed sensing networks capable of collecting vast quantities of data at a widely distributed spatial scale. These networks are often owned and operated by place owners that would not have been able to support or justify a similar scale of network using more-costly higher-performance technologies.

Large new data sets have higher levels of uncertainty and lower levels of trust associated with them, and remain difficult to make use of until new data interpretation and modelling methodologies can be developed. However, as such capabilities now start to emerge, place-owners have access to data with the potential to support powerful new areas of impact, that cannot be served using smaller-scale data collection approaches. With technologies and supporting methodologies still in their relative infancy, it seems likely that a paradigm shift in smart sensing is underway, with the potential to drive innovative new solutions to critical challenges.

References to illustrate the widespread use of the term 'low-cost' sensing

Use of the term by notable organisations:

- The United Nations Environment Program (air quality)
- The US Environmental Protection Agency (air quality)
- The UK Department for Environment Food and Rural Affairs (DEFRA) (air quality)
- Australian State of the Environment Report (2021) (air quality)
- CSIRO (water quality monitoring)
- CSIRO (smart viticulture irrigation management)
- CSIRO (ocean monitoring)
- US Irrigation Association (irrigation)

Academic citations for 'low-cost' soil moisture sensing devices:

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- Valera, H. A., & Luštrek, M. (2022). Deploying Low-Cost and Full Edge-IoT/AI System for Optimizing Irrigation in Smallholder Farmers Communities. *Workshops at 18th International Conference on Intelligent Environments (IE2022)*

C COSTS

Fixed and variable costs

The 'fixed' costs in these tables are costs that do not scale down past a certain base rate, regardless of the size of site, the number of deployed devices (or gateways), or the complexity of a site (e.g. topography, soils, vegetation, irrigation requirements).

The 'variable' costs in these table are costs that *do* vary (often above a fixed baseline) relative to the size of site, the number of deployed devices (or gateways), or the complexity of a site (e.g. topography, soils, vegetation, irrigation requirements).

Table C1. An overview of fixed and variable capex for project establishment

Establishment	Fixed	Variable
Project management		
Project management	Base rate of engagement will have a minimum effort. Even small simple projects will have enough complexity that this role should be considered vital to success.	Additional effort relating to project complexity (number of partners, complexity of data architecture, end user requirements, etc.) will demand more time and cost.
IoT system design and integration management		
IoT system design and integration management	Base rate of engagement will have a minimum effort. Even small simple projects will have enough complexity that this role should be considered vital to success.	Additional effort relating to complexity of data architecture (which should not vary with scale of site or size of device network) will demand more time and cost.
Collation/production of technical documentation	Baseline effort of document production – includes content that does not vary with system complexity	Variable by system complexity
Sensing devices		
Procurement	Labour relating to research, management, approvals, administration	*None*
Sensing devices (hardware, configuration and onboarding)	*None*	Variable by number of devices
Additional mounting hardware: custom mounting infrastructure extensions (e.g. masts); custom mounting solutions (e.g. brackets and connectors)	Design, approval and fabrication setup are fixed, regardless of units	Variable by number of devices
Device communications (assumes LPWAN with private gateways[1])		
Procurement	Labour relating to research, management, approvals, administration	*None*
Communications hardware (gateway hardware, gateway configuration)	*None*	Variable by number of gateways

Establishment	Fixed	Variable
Communications service (year 1 – consider this to be an establishment cost as it is required as part of establishment activities)	Fixed for ~<500 devices (i.e. does not vary whether you connect 1 or 499 devices)	Higher tier service fees for LoRaWAN only arrive at ~500+ devices Similar business models for Sigfox and NBIoT
Gateway deployment planning and approvals	Site visits, correspondence, design work, documentation, engineering assessment, revisions, partner and contractor liaisons	Total effort increases with scale and complexity of site
Gateway installation	Planning, administration, correspondence, hire of height access machinery.	Fixed costs increase with multiple gateways, though less so if deployments are alike. Multiple deployments in different contexts with bespoke solutions lead to more variability. Sites with more complex topography require a minimum of two gateways for redundancy, regardless of the number of devices.
Sensing device network planning and deployment		
Sensing device network planning and approvals	Site visits, correspondence, proposal documentation, revisions, partner and contractor liaisons	Total effort increases with scale and complexity of site
Sensing device installation	Production/adaptation of installation guidance documentation (project staff hours) Time spent training contractor (project staff hours) Baseline contractor engagement fee	Assembly and labelling of devices prior to installation (project staff hours) Contractor fee varies by number of units (though there are commonly discounts for larger batches)
Management and oversight of the deployment process Verification and troubleshooting of devices and data	Baseline responsibility will be assigned to one or more service providers, with a fixed cost for small scale networks. For SIMPaCT this role was fulfilled by UTS	Variable by number of devices
Device management and technical support during project establishment phase (to support activation, verification and troubleshooting)	Baseline responsibility will be assigned to one or more service providers, with a fixed cost for small scale networks. For the SIMPaCT pilot, this was split between two commercial device management contractors (The ARCS Group; CTS)	Variable by number of devices Most contractors will offer services that align with brackets of demand (e.g. 1-20 devices has a starting rate; 20-50 devices has rate #2; etc.), rather than being determined on a per/unit basis.
Sensing device network documentation	Baseline effort of document production – includes content that does not vary with device numbers	Variable by number of devices
Metadata		
Metadata schema adaptation	Engagement with new site, new irrigation system, new end user requirements.	Varies with complexity of a new site

Establishment	Fixed	Variable
	Liaison with technical team and documentation of changes	
Metadata capture	Engagement with site owner, site visits	Varies with site size and complexity of new site
Platforms and services		
License fees (year 1)	Fixed annual rate: • IoT platform(s) (number may vary) • Data management platform • Biophysical model	*None*
Platform/model instantiations	Fixed rate for establishment of: • IoT platform(s) (number may vary) • Data management platform • Biophysical model • Machine learning model • Other key digital twin components	*None*
Platform hosting	Base rates for IoT platform(s) and Data management platform (e.g. to AWS)	Variable costs based on size of system and required processing power (relating to the number of stations, etc.)
Database establishment and customisation	Instantiation of a new database instance for telemetry and metadata storage, with a structure aligned to updates in the data model. Permissions/access setup and management.	*None*
Irrigation management platform customisation	Integration with the Data management platform	*None*
IoT platform customisations	Integration of IoT Platform(s) with new sensing device type(s) (depends on choice of sensing devices)	*None*
Data management platform customisations	Integration of Data management platform with new Irrigation management system, including the creation of a new custom adapter. Integration of Data management system with new IoT platform(s) (depends on choice of sensing devices) Updates to the data management model within the Data management platform, to accommodate new telemetry sources, metadata changes, and new irrigation system integration.	*None*

Establishment	Fixed	Variable
	End user engagement and configuration of system settings (relating to workflows, alert customisation, etc.)	
Biophysical model training	Collection of three months data. Correction, harmonisation, cleaning and quality control of training data. Model training	*None*
Dashboard creation and first year of hosting (optional)	Instantiation, hosting, customisation, design/sleeve	*None*
Operationalisation and handover		
Workflow integration	Integration of the SIMPaCT solution with existing irrigation management workflows, in collaboration with irrigation contractors. Effort is unlikely to vary with scale.	*None*
Training of irrigation contractors and land owner	Production of training materials Delivery of training sessions Ongoing support	*None*

Table C2. An overview of fixed and variable costs for ongoing operation of the SIMPaCT digital twin

Operations	Fixed	Variable
Administration and oversight		
Administration and coordination of all operations - either by the place owner (e.g. SOPA), or as a service provided by a third party.	Managing the contracts, payment, reporting, etc. relating to: • Communications services • On-the-ground management of the sensing network • Technical support (for each device vendor) • Platforms and services	*None*
Oversight and strategic management (within place owner organisation)	Fixed baseline of effort for small to medium scale	Potentially additional effort for higher complexity and higher expenditure operations.
Device communications (assumes LPWAN[3])		
Account/network service fee p.a. (maintenance of the gateway/s and the IoT network including periodic upgrades to maintain connectivity to evolving network standards, rectification of faults, configuration updates and remote monitoring and alerting)	A per customer fixed annual rate	*None*
Per/Gateway management fee p.a	Fixed minimum for one gateway	Variable by number of gateways
Dashboard and Visualisation Tool (50 Devices) fee p.a.	Fixed for systems with 50 or less devices	Variable by number of devices, for networks >50 devices

Operations	Fixed	Variable
Network server access fee p.a.	Fixed for systems with 250 or less devices	*None* (Variable by number of devices, but only for networks >250 devices)
Sensing network operations		
On-the-ground management (Physical day-to-day management of deployed hardware, including: checking status reports, fault diagnosis and troubleshooting, firmware updates, reconfiguration, battery replacement, decommissioning, replacement, re-location, metadata/documentation updates, liaising with tech support and place owner)	A low fixed annual engagement fee that will likely not scale past a certain minimum size of network.	Variable by number of devices (above a fixed baseline)
Annual technical support fee for each device vendor (troubleshooting support, over the air updates, return to base, fix/refurbish)	A low fixed annual engagement fee that will likely not scale past a certain minimum size of network.	Variable by number of devices (above a fixed baseline)
Auditing and reporting	Periodic (e.g. quarterly) audits and reports on the 'health' and functionality of the sensing device network. Effort will be fixed for smaller networks (e.g. 1-20)	Variability of effort/time/cost may arise with larger networks
Periodic workflow and training updates	Regardless of the scale of the system, there will be periodic changes to how it operates (resulting from iterative improvements across all instances) that require irrigation managers to updates their workflows and staff. These will likely consist of updated operational documents, and training sessions. The time and cost associated with this will not scale with site or sensing network size.	*None*
Metadata and documentation management		
Updates to system metadata (Constant updates are required to ensure system functionality)	A fixed responsibility for the IoT platform provider and the data management platform provider	Work/effort increases with the scale of the device network and the size and complexity of the site.
Platforms and services		
License fees p.a.	Fixed annual rate: • IoT platform(s) (number may vary) • Data management platform • Biophysical model	*None*
Platform/Data hosting	Fixed annual rate: • IoT platform(s) (number may vary) • Data management platform • Biophysical model	Fees will scale above a hosting baseline, relative to data storage requirements (which relates to number of devices)
Biophysical model operation (p.a. service fee)	Twice-yearly calibration and validation, data quality assurance, model updates relating to in-park hardware adjustments, etc.	Potential additional effort for larger scales (e.g. more quality assurance)
Dashboard hosting	Fixed annual rate	

Cost estimates

Tables C5 and C6 illustrate the broad range of activities involved in establishing and operating a standalone instantiation of the SIMPaCT solution at a new location. Upper and lower costs are estimated for each deliverable or activity, with the broad range between these two estimates serving to highlight the difficulty in providing firm guidance on the possible future cost of SIMPaCT. The critical output of these tables are the lower cost estimates, as they are roughly indicative of a minimum cost for standalone SIMPaCT solutions that cannot be reduced regardless of scale.

The minimum cost estimate calculated for this report is unlikely to be achieved in practice. Each line item has an associated effort and value that is conservatively low, in order to demonstrate a theoretical minimum lowest cost for project establishment. The conditions and size of any future real world project are extremely unlikely to match this. The estimated cost for any new project should be assessed and costed against a specific context and end user requirements.

Methodology for completion of the tables

Tables C5 and C6 have been completed based upon the general structure and approach of the SIMPaCT 1.0 pilot project. The digital twin architecture remains the same (with room for some simplification), and the same general tasks and roles are repeated. These are scaled right down for 'low estimates', allowing some degree of simplification (e.g. a handful of devices, minimal customisation, no further development of the solution, etc.). The assumption is that the deployment context is still on a piece of land owned and managed by an organisation (as opposed to a private residence), that the site has existing irrigation in place, and that the end user requirements align with one or more of the four main value propositions for SIMPaCT.

Upper estimates are to some extent more arbitrary, as one might imagine deployment at far larger scales, over longer time periods. The upper estimate figures have been selected with a slightly larger site that Bicentennial Park in mind, a similar 18-month project period, and the most costly/complex solutions that might reasonably be required for each line item (e.g. top-of-the-range sensing devices, extensive customisation). The total number of soil moisture sensors required has been halved based on learning from the pilot project. The main point of the upper estimates is to provide a contextual reference for the lower estimates, and an overall range (between lower and upper estimates) for replication of the existing SIMPaCT solution as a standalone instantiation.

Lower estimate scenario	Upper estimate scenario
• 2 soil sensing devices (plus 1 reserve) • 1 ambient temperature/RH sensing devices (plus 1 reserve) • 1 weather station • 1 LoRaWAN gateway • Up to 4 stations • 6-month project delivery period • Minimal site complexity • Limited customisation • Very low estimates for licensing, instantiation, configuration, hosting and support for platforms and dashboards	• 100 soil sensing devices • 50 ambient temperature/RH sensing devices • 31 weather stations • 5 LoRaWAN gateway (assuming a larger and more complex site, and a desire to eliminate signal blackspots for more reliable data collection) • Up to >200 stations • 18-month project delivery period • High site complexity • Extensive customisation • High estimates for licensing, instantiation, configuration, hosting and support for platforms and dashboards

All rates are conservatively estimated based off knowledge of current 2023 pricing. Neither lower nor upper rates directly relate to actual commercial costs for SIMPaCT 1.0. Lower rates are deliberately lower and upper rates are deliberately higher. By taking a conservative approach to low rates (i.e. using significantly 'low-ball' estimates), we aim to avoid debate about actual costing for each item and establish rapid consensus (i.e. lower rates will always be uncontroversial). This allows us to add together all line items and arrive at a rough conservative estimate for the lowest possible threshold cost that all readers should agree on.

It should be noted that the estimates do not include the extensive effort required in the pilot project for the original development of the SIMPaCT solution. The lower and upper totals for project establishment reflect the application of SIMPaCT in its current form, using the work of the pilot project as a foundation. The lower estimate assumes almost no additional customisation or further development work will be needed. The upper estimate assumes more extensive customisation but no further development work. The degree to which customisation and development work will be required cannot be resolved until SIMPaCT 2.0 projects are run and provide a real-world context for assessing these questions.

The precise figures for the estimates are a product of the methodology and can be rounded to the nearest five thousand dollars for simplicity. A margin of error of +/-20% is added in recognition of how these figures are only meant to be roughly indicative. The -20% figure for the lower estimate can then be adopted as a final conservative output.

Some other working assumptions were required to enable completion of the table:

- 1 day = 7 hours
- Manual labour (e.g. installation) rate range of $100-$200 per hour
- Skilled/professional labour (e.g. project management, development, design, etc.) rate range of $140-$200 per hour

Discussion of table outputs

The lower estimate for project establishment

The lower estimate for project establishment rounds to $90,000 with a ~$35,000 (+/-20%) error range between ~$70,000 and ~$105,000. The figures suggest that the lowest possible establishment cost for a standalone instantiation of the SIMPaCT solution would be somewhere in the region of $70,000, with a strong chance of the true lower figure being somewhat higher than this.

A limitation of this lower estimate for project establishment is that it assumes a scaling down of the established pilot approach. It does not accommodate, for example, a simplified off-the-shelf commercial adaptation of SIMPaCT designed for residential use. We do not know if such an application would be possible or have a workable business model, but it is clear that it would require major fundamental changes to the solution (to the digital twin architecture, to the functional capabilities, to the methodology, and to the supporting materials). We do not wish to rule out such a possibility, however it lies outside the scope of this cost assessment exercise.

The lower estimate for operations

The lower estimate for project operations rounds to $35,000 with a ~$15,000 (+/-20%) error range between ~$25,000 and ~$40,000. The figures suggest that the lowest possible annual operational cost for a project of this kind would be somewhere in the region of $25,000, with a strong chance of the true lower figure being somewhat higher than this.

Note that the lower cost scenario for operations ignores all potential cost associated with administration and oversight, as it is assumed that these tasks would be taken on by pre-existing staff within the place-owner organisation and would not count as an additional cost. For the upper cost estimates, these costs have been included.

Alternative cost estimates based on NBIoT communications

The cost estimates presented so far assume the use of LoRaWAN as the communications technology for smaller IoT devices (soil moisture, ambient temperature and humidity). LoRaWAN is part of the LPWAN family of technologies. LPWAN enables low power devices and is likely to be critical for supporting soil moisture sensing devices with no above-ground profile and a battery life measured in years (rather than in weeks). LoRaWAN (and its close cousin Sigfox) require local gateways, the procurement, deployment and operation of which can add considerable cost to a project. Private LoRaWAN tends to make good business sense at scale, as there is no marginal cost for each device on the network. It may become less cost competitive for smaller networks. Here, NBIoT becomes a viable alternative option, provided the spatial context is amenable.

Narrowband IoT (NBIoT) is a machine-to-machine LPWAN communications protocol that operates over the existing network of 4G/LTE mobile communications towers. Its low power consumption is comparable to LoRaWAN and it is cost competitive for smaller network deployments (100s of devices, as opposed to tens of thousands). One drawback of NBIoT is that, due to reliance on existing mobile infrastructure (rather than on private gateways), there is no ability to adjust NBIoT coverage to suit the specific deployment needs of a project, though this is somewhat offset by the superior signal penetration. NBIoT may prove a challenge for locations such as Bicentennial Park, with undulating topography, dense soils and high tree cover. However, in simpler contexts with more open ground, lower clay content, and sparser tree coverage, NBIoT becomes a strong option.

Using pricing published by leading Australian NBIoT provider M2MOne, we can estimate the lower and upper cost scenarios using NBIoT, and compare this to LoRaWAN (Table C3 and Table C4).

Table C3. Lower estimates for LoRaWAN vs NBIoT

Lower	Establishment cost for data communications (incl 1 year operations)	Annual operations cost for data communications	Complete lower cost scenario estimate for project establishment	Complete lower cost scenario estimate for operations
LoRaWAN	$9380	$3500	~$90,000	~$35,000
NBIoT	$2166	$849	~$80,000 -20% = ~$65,000 +20% = ~$100,000	~$30,000 -20% = ~$25,000 +20% = ~$35,000

Table C4. Upper estimates for LoRaWAN vs NBIoT

Upper	Establishment cost for data communications (incl 1 year operations)	Annual operations cost for data communications	Complete lower cost scenario estimate for project establishment	Complete lower cost scenario estimate for operations
LoRaWAN	$126,300	$9500	~$1,654,825	~$178,950
NBIoT	$10,263	$6879	~$1,448,525	~$176,329

These cost estimates show that NBIoT is a more cost-effective solution, with significant savings for the low cost (small network) scenario, and for the upper cost estimate (large scale network[5]). **The key takeaway from this assessment of NBIoT is that the estimated minimum cost for establishment of a future standalone instantiation of the SIMPaCT solution can be dropped from ~$70,000 to ~$65,000**. The lower cost estimate for overall system operations remains unchanged (to the nearest $5,000).

It should be noted that the very high upper estimate for LoRaWAN assumes a $100k installation cost. However, even if this is disregarded, NBIoT retains a significant competitive advantage over LoRaWAN. For sites that are less complex than Bicentennial Park, NBIoT should be considered as a strong alternative future option.

The use of NBIoT relies upon suitable NBIoT-based IoT devices for soil moisture sensing and ambient temperature/humidity sensing, both of which are commercially available options. Low-cost soil moisture sensing devices are available at the same cost (~$200 per unit) and low-cost ambient temperature and humidity sensing devices are available at ~$300 per unit. The cost estimates for NBIoT account for the slight rise in unit cost for ambient temperature and humidity sensing devices.

Estimating the cost range of establishment

Table C5. A table showing the calculation of lower and upper estimates for establishing a new standalone instance of the SIMPaCT Solution at a new site (assuming LoRaWAN communications)

-20%	+20%	-20%	+20%
$70,528	*$105,792*	*$1,323,860*	*$1,654,825*
	$88,160		**$1,654,825.00**

Item	Breakdown	Description	Lower estimate	Upper estimate
Project management	Project management	• Management of all aspects of the project. Notably: governance lead, procurement, contractor management, stakeholder liaison, administration, reporting. Rates will vary significantly depending on contractor. Highly dependent upon total project period and FTE	~$140/hr Assume a minimum establishment period of 6 months, and 0.1fte = **~$12,740**	$200/hr Assume an 18-month project period with 0.4fte = **~$218,000**

Item	Breakdown	Description	Lower estimate	Upper estimate
	Oversight	Oversight and strategic management (within place owner organisation)	Assume $140/hr Assume 1hr/month for 6 months **Total = $840**	Assume $350/hr Assume 4hr/month (meetings + correspondence) for 18 months **Total = $25,200**
IoT system design and integration management	IoT system design and integration management, and documentation	• Optimisation of architecture and system design to meet end user requirements and place context. • Management of system integration, working with all technology providers. • Collation/production of technical documentation Rates will vary significantly depending on contractor. Highly dependent upon total project period and fte.	~$140/hr for 20 days = **$19,600**	$200/hr for 60 days, roughly equivalent to **$84,000**
NOTE: It may be possible to merge the roles of project management and IoT system design and integration management to achieve cost savings. Based on the lower estimates for both tasks, we can conservatively suggest a combined cost of $20K for a 6 month project.			**$25,000**	*NA*
Smart sensing devices	Hardware	• Soil moisture sensing devices • Ambient temperature and humidity sensing devices	$200 per unit Assume minimum order of three soil moisture units and two T/RH nodes (with spares/redundancy) for a small-scale network **Total = $1000**	>$3000 per unit (e.g. for high-performance soil moisture sensing devices) $1000 per unit for high-performance LoRaWAN T/RH devices Assume 100 soil moisture sensing devices (*half* the total number used for SIMPaCT) + (20 reserve) Plus 50 T/RH devices + (5 reserve) **Total = $350,000**
		• Weather stations	$2-3K per unit Assume one unit for a small-scale network **Total = $2000**	>$10K per unit (high performance) Assume 13 units (equal to SIMPaCT 1.0) **Total = $130,000**
	Configuration, onboarding and integration of all devices	• Configurable device settings fixed to user requirements • Onboarding of devices to their respective IoT platforms • Integration of device data streams into SIMPaCT	$50 per unit (broadly representative of industry standard) Assume minimum order of five units for a small-scale IoT network, with spares/redundancy = $250 Plus $200 for one weather station **Total = $450**	>$200 per unit (would apply to more complex devices with LTE setup and many configurable settings) Assume 150 small-scale IoT devices and 13 weather stations **Total = $33,000**
Sensing device deployment costs	Custom extension/adaptation of existing mounting infrastructure	The addition of extension poles to enable deployment of devices in critical locations.	**$0** (none required)	Several thousand dollars for large masts in complex locations with

Item	Breakdown	Description	Lower estimate	Upper estimate
		• Assessment of existing infrastructure and design of prototype solutions • Fabrication and installation of prototypes • Detailed documentation of final design proposal • Approval of final designs (admin/correspondence) • Installation and expendables The total number of these custom extensions will vary by site and by the number of devices to be deployed and cannot be usefully estimated.		high engineering requirements Assume $70,000 as a reasonable upper estimate for a multi-weather station deployment using custom masts (inclusive of engineering fees, labour, height access equipment hire, etc.) Assume 50x pole extensions for T/RH devices @$200 each = $10,000 **Total = $80,000**
	Additional device mounting hardware	Most devices do not have out-of-the-box mounting solutions that are appropriate for a specific project context, and will require additional mounting hardware such as brackets, straps, or clamps for pole-mounted devices, or tubes, valve boxes and stakes for soil moisture sensors.	Assume $30 per unit as a common lower estimate for smaller IoT devices, with three soil devices and two T/RH = $150 Assume 1x $250 for a weather station **Total = $400**	Assume $50 per unit for 100 soil and 50 T/RH devices = $7,500 Assume 13x $250 = $3250 **Total = $7825**
Planning and delivery of an onsite smart sensor network	Sensing device deployment methodology	Although SIMPaCT identified a recommended device deployment methodology, contextual differences between sites mean that a single fixed approach is unlikely to work optimally for all future locations. As such, a process of planning and optimisation will always be required. • Initial trial deployment, using standard prescribed SIMPaCT methodology • Production of variation documentation, based on trial • Approval	1 day, 2 people Assume $140/hr 14 hours total **= $1960**	5 days, 2 people Assume $140/hr 70 hours total **= $9800**
	Deployment planning	• Determine locations of interest for sensing device deployment • Site surveys and on-the-ground communications signal testing • Deployment planning documentation compiled and submitted • Response to feedback and variations	3 days, 2 people Assume $140/hr 42 hours total **= $5880**	20 days, 2 people Assume $140/hr 280 hours total **= $39,200**

Item	Breakdown	Description	Lower estimate	Upper estimate
		• Final plan and deployment instructions compiled and agreed • Devices and mounting solutions finalised and procured, as per the approved deployment plan • Devices received, assembled and labelled ready for deployment • Devices tested and verified prior to deployment		
	Device installation	This varies by the size and complexity of the device. Small low-cost sensors on poles are the lowest cost. Soil moisture sensors take more planning and time. Weather stations are large and bulky and require the most time and additional equipment.	Assume $100/hr Small device installs: Assume two people for a minimum of half an hour of labour. Assume 5x 1hr install per device = $500 Weather station install: Assume two people for 2hrs (1x 4hr) = $400 **Total = $900**	Assume $200/hr Small device installs: Assume two people for a minimum of half an hour of labour. Assume 150x 1hr install per device = $30,000 Weather station install: Several thousand dollars for complex installs (particularly for plant hire for height-access). Assume 13 weather stations @4hrs each = $10,400 (plus $30K for plant hire) **Total = $40,400**
	Sensing device trouble-shooting and technical support	• Review device activity to ensure proper functioning (produce initial audit) • Determine cause of issue with faulty devices • Plan and conduct troubleshooting activities, including site visits if required • Finalise all deployment metadata and submit • Includes relocation support and configuration updates for existing deployed devices, as required Generally speaking, these costs should be grouped into a support package by the device vendor. There may be multiple different support packages for different device types. Troubleshooting generally requires the time of other parties, in addition to the vendor, both in correspondence and on	Assume $140/hr 5 days, two people = 28 hours **Total = $9800**	Assume $200/hr Assume 4 people, 2 days per week for 8 weeks = 448 hours **Total = $89,600**

Item	Breakdown	Description	Lower estimate	Upper estimate
		site. These include the site owner, project manager, and/or other project support personnel (e.g. a role covered by UTS in the pilot project)		
Data communications	Communications hardware (gateway hardware, gateway configuration)	Costs vary significantly, depending on the technology used. Very low-cost sensing devices with low power demand, of the type used for SIMPaCT, tend to require LPWAN communications such as LoRaWAN, SigFox, NBIoT or similar. This costing scenario assumes the use of LoRaWAN, which was used for the SIMPaCT pilot. Costs may be broken down into: • Gateway hardware • Gateway mounting hardware (custom masts, brackets, etc.) • Shipment of gateways and mounting hardware • Gateway Configuration, Testing and Commissioning • Radio Frequency mapping • Deployment planning, project management and approvals • Gateway site inspection • Engineering design and approvals for gateway installation • Power supply equipment and custom electrical works • Installation Services	1 gateway @~$3k per gateway = $3000	5 gateways @~$3K per gateway = $15,000
	Gateway deployment planning and approvals		Assume $140/hr 1 day, 1 person 7 hours **= $980**	Assume $200/hr 3 days, 4 people 84 hours **= $16,800**
	Gateway installation		Assume 1 gateway, no height access equipment, no extension masts, basic electrical work **= $1900**	Assume five gateways, height access equipment, extension masts, extensive engineering work, complex electrical work ~$10-20k per gateway **Total = $100K**
	Communications service (year 1 – consider this to be an establishment cost as it is required as part of establishment activities)	The fee payable for communications access, maintenance and technical support + per/gateway fee	1 gateway **Total = $3,500 p.a.**	5 gateways **Total = $9,500 p.a.**
Platforms and services	License fees (year 1) + Platform/model instantiations + Platform hosting + Database establishment and customisation +IoT platform customisations	Annual licence: • IoT platform(s) (number may vary) • Data management platform • Biophysical model Instantiation: • IoT platform(s) (number may vary)	Minimum: 1x IoT platform 1x Data management platform 1x Irrigation management system 1x primary database (associated with data management platform)	Hardened commercial systems with extensive additional functionality, strong SLAs, high data use, high processing rates, and extensive custom development, may have associated fees that are several tens or

Item	Breakdown	Description	Lower estimate	Upper estimate
	+ Data management platform customisations	• Data management platform • Biophysical model • Machine learning model • Other key digital twin components • new database instance for telemetry and metadata storage, with a structure aligned to updates in the data model Hosting: • IoT platform(s) and Data management platform hosting costs (e.g. to AWS) Setup/configuration: • Permissions/access setup and management. • Updates to the data management model within the Data management platform, to accommodate new telemetry sources, metadata changes, and new irrigation system integration. • End user engagement and configuration of system settings (relating to workflows, alert customisation, etc.) • Integration of IoT Platform(s) with new sensing device type(s) (depends on choice of sensing devices) • Irrigation management platform customisation System integrations: • Integration of Data management platform with new IoT platform(s) (depends on choice of sensing devices) • Integration of Data management platform with new Irrigation management system, including the creation of a new custom adapter. • Integration of irrigation management data feed with the Data management platform	General market rates for instantiation of basic platforms with configuration of *existing* settings begins at around ~$5K for simple platforms, with another ~$5K p.a. for licensing, full use and tech support. Assume the irrigation management platform is already in place. Thus only two new platforms need instantiating, at a lower estimated total of $20,000 (incl. license fees). Assume that base rates above cover hosting and data storage at no additional cost. Custom development and integration for data management and irrigation control platforms is required as bare minimum. Assuming a conservative minimum effort, allow $2K for each platform = $4,000 **Total = $24,000** for the most basic standalone instantiation of SIMPaCT architecture (this is likely well under true minimum costs but works fine as part of the overall conservative lower estimate)	even several hundreds of thousands of dollars. Due to vast variability, it is not possible to usefully place upper figures on line item. However, we can multiple the lower estimate by 10 to gain a usable working figure to put towards the total for this column. **Total = $240,000**
	Biophysical model training	Correction, harmonisation, cleaning and quality control of training data.	Assume $140/hr Assume the most basic possible effort =	Assume $200/hr Assume extensive data quality control, cleaning,

Item	Breakdown	Description	Lower estimate	Upper estimate
		Model training	2 hours (following data collection) + some additional fees (admin, baseline engagement costs, etc.) **Total = ~$350**	correction and harmonisation, or a large data set. Multiply lower estimate by 10 **= $3,500** (~17.5 hrs work)
	Dashboard creation and first year of hosting (optional)	Instantiation, hosting, customisation, design/sleeve	**$1000** (Assuming this is well below the true lower value)	**$50,000** A rough upper estimate for a high-production customised website and data portal.
Operationalisation and handover	Workflow integration	Integration of the SIMPaCT solution with existing irrigation management workflows, in collaboration with irrigation contractors. Includes documentation.	Assume $140/hr Assume min effort by 4 people (as it involves multiple contractors) for 1 day = 28hrs **Total = $3920**	Assume $200/hr Assume effort by 8 people for 2 days = 112hrs **Total = $22,400**
	Training of irrigation contractors and land owner	Production of training materials Delivery of training sessions Ongoing support	Assume $140/hr for all parties Assume no changes to basic materials. Assume 1 session of 2 hours of direct training. Assume minimum effort by at least four people (two trainees and two trainers) = $1120 Assume retainer for support at annual minimum rate of $1000 **Total = $2120**	Assume $200/hr for all parties Assume changes to basic training materials requiring 2 people 1 day = 14 hours = $2800 Assume 4 sessions of 2 hours of direct training. Assume minimum effort by at least 8 people = $12,800 Assume retainer for support at annual minimum rate of $10,000 **Total = 25,600**

Estimating the cost range of future operations

Table C6 A table showing the calculation of lower and upper estimates of annual costs for a standalone instance of the SIMPaCT Solution (assuming LoRaWAN communications)

-20%	*+20%*	*-20%*	*+20%*
$27,200	*$40,800*	*$143,160*	*$214,740*
	$34,000		**$178,950**

Item	Breakdown	Description	Lower estimate	Upper estimate
Administration and oversight	Administration	Administration and coordination of all operations – either by the place owner (e.g. SOPA), or as a service provided by a third party.	~$140/hr Assume 1 day per month = 7x12 = 84 hrs p.a. = $11,760 Note: this may be discounted as a direct cost if the role is assumed by a pre-existing position within the lead organisation. The figure represents 'true' cost to the organisation. For our purposes (determining a lower operational cost	$200/hr Assume 2 days per month, or roughly half a day per week (allowing for management of additional complexity) = 7x24 = 168 hrs p.a. **= $33,600** We will include this figure in the upper estimate as we should assume that the lead organisation wishes to cover the true

Item	Breakdown	Description	Lower estimate	Upper estimate
			estimate) we will discount this figure.	cost as part of this scenario.
	Oversight	Oversight and strategic management (within place owner organisation) We may assume that in any scenario, a project would be incorporated into a broader portfolio of oversight responsibilities at negligible cost to the lead organisation. Max effort would likely entail reading and responding to reports, and discussing SIMPaCT at board meetings)	$0	Assume $350/hr Allocate 3hrs p.a. (meetings + correspondence) **Total = $1,050**
Device communications (assumes LoRaWAN)	Account/network service fee p.a.	Maintenance of the LoRaWAN gateway/s and the IoT network including periodic upgrades to maintain connectivity to evolving network standards, rectification of faults, configuration updates and remote monitoring and alerting. Includes dashboards and network server access.	**$2000**	**$2000**
	Per/Gateway management fee p.a		Assuming one gateway **= $1500**	Assuming 5 gateways = $7500
Sensing network operations	On-the-ground management	Physical day-to-day management of deployed hardware, including: checking status reports, fault diagnosis and troubleshooting, firmware updates, reconfiguration, battery replacement, decommissioning, replacement, re-location, metadata/documentation updates, liaising with tech support and place owner	Assume $100/hr Assume 0.5hr/wk for a small network of 1 soil device, 2 T/RH devices and 1 weather station (26 hours p.a.) **= $2600 p.a.**	Assume $200/hr Assume 2hr/wk for a large network of 100 soil, 50 T/RH and 13 weather stations (104 hours p.a.) **= $20,800 p.a.**
	Annual technical support fee for each device vendor	Troubleshooting support, over the air updates, return to base, fix/refurbish (needs to consider a base engagement rate)	Assume $140/hr Assume 0.5hr/wk for a small network of 1 soil device, 2 T/RH devices and 1 weather station (26 hours p.a.) **= $3,640 p.a.** *Note: Minimal effort is conceivably lower. However, a base engagement rate, and the need to ensure contingency for more complex issues, means that we should not take this figure any lower.*	Assume $200/hr Assume 2hr/wk for a large network of 100 soil, 50 T/RH and 13 weather stations (104 hours p.a.) **= $20,800 p.a.**

Item	Breakdown	Description	Lower estimate	Upper estimate
	Auditing and reporting	Periodic (e.g. quarterly) audits and reports on the 'health' and functionality of the sensing device network. Effort will be fixed for smaller networks (e.g. 1-20) This task will likely be divided between IoT platform providers.	Assume $140/hr Allow 1hr per audit/report (assume that a degree of automation is built into the system) Quarterly reports = 4hrs **Total = $560**	Assume $200/hr Allow for additional complexity of diagnosing and reporting on issues for a large device network. Assume 3.5hrs per audit/report. Quarterly = 14 hours **Total = $2800**
	Periodic workflow and training updates	Regardless of the scale of the system, there will be periodic changes to how it operates (resulting from iterative improvements across all instances) that require irrigation managers to update their workflows and staff. These will likely consist of updated operational documents, and training sessions. The time and cost associated with this will not scale with site or sensing network size.	For updates to the documentation and training materials: Assume rate of $140/hr. Assume 0.5 days per quarter (2 days p.a.) = 14 hours = $1960 For training session delivery: Assume rate of $140/hr. Assume 2x1Hr sessions p.a. = $280 For trainees attending sessions, assume this is covered by existing engagement responsibilities. **Total = $2240**	Assume rate of $200/hr Assume 0.5 days per quarter (2 days p.a.) = 14 hours **= $2800**
Metadata update management	Updates to system metadata	Constant updates are required to ensure system functionality. Tasks include correspondence with contractors and platform providers. Likely to be merged with administration responsibilities	Assume rate of $140/hr Assume 0.5 days per quarter (2 days p.a.) = 14 hours **= $1960**	Assume rate of $200/hr Assume 1 day per quarter (4 days p.a.) = 28 hours **= $5600**
Platforms and services	License, platform, hosting fees p.a.	Fixed annual rate: • IoT platform(s) (number may vary) • Data management platform • Biophysical model	Assume $5000 p.a. as a minimum amount for each of the three platforms listed, with the four-device network proposed. **Total = $15,000**	Assuming the larger device network proposed, assume additional hosting, data storage and data processing requirements for all platforms. Assume two IoT platforms. Assume $10-25K per platform. Rough estimate of = $40,000 to $100,000 p.a *Difficult to estimate more clearly without more context.* For our purposes, we will use the average of these two values to contribute to the total for this column **= $70,000**
	Biophysical model operation (p.a. service fee)	Data quality assurance, model updates relating to in-park hardware adjustments, etc.	Twice-yearly calibration and validation Assume a baseline engagement fee of no less than **$3500 p.a.**	Assume $200/hr rate Assume 5 days p.a. (to accommodate larger data sets and quarterly calibration for greater

Item	Breakdown	Description	Lower estimate	Upper estimate
				model accuracy and risk mitigation) = 35 hours **= $7000 p.a.**
	Dashboard hosting	Hosting and maintenance of the website and public dashboard	Assume a minimum baseline of **$1000 p.a**. regardless of the number of devices or amount of data flow.	Difficult to estimate, however we can assume that the cost does not correlate strongly with size of sensor network. A rough upper estimate of **$5000** p.a. seems reasonable (though it may conceivably go much higher, depending on the level of active support required for a live data portal).

D SIMPACT ATTRIBUTES

Any digital platform, or larger integrated digital system (comprising multiple platforms, services, devices and databases), can be assessed according to fifteen standardised attributes or *quality criteria* (see Table D1). By assessing the SIMPaCT digital twin against these criteria (see Table D2), we can gain insight into the strengths and weaknesses of the current system, and its ability to mature into a scaled and hardened solution in the coming years.

Table D1. An overview of the fifteen quality criteria for assessing the SIMPaCT digital twin

	Criteria
Relatability How well the components of a system **relate and link** to each other.	Integration
	Interoperability
	Portability
Compatibility How well the components of a system are **compatible** with **and adaptable** to the needs of an operating **environment.**	Hosting
	Supportability
	Security
	Auditability
	Scalability
Functionality How well the system **functions** relative to **needs**, once it is established or in operation.	Availability
	Reliability
	Performance
User experience How well the system **functions** meet the **user experience needs**, once it is established or in operation.	Usability
	Reporting
	User Support
	Training

Table D2. A detailed assessment of the SIMPaCT digital twin against fifteen quality criteria

Quality criteria	Description	Comment
1. Integration	Integration refers to the ability of a platform or service to integrate with other platforms or services to form a large complete functional system that meets the needs. It may require high levels of custom development to achieve and does not necessarily require good interoperability.	The SIMPaCT digital twin is built around the integration of multiple platforms and services. The Irrigation adaptor module is designed with connector applications that integrate various commercial irrigation management systems with the SIMPaCT digital twin. The Senaps platform is capable of ingesting and harmonising a wide variety of live data, from any IoT platform or third-party API.

Quality criteria	Description	Comment
2. Interoperability	Interoperability refers to the ability of a platform or service to exchange data and integrate functionality via common shared language and protocols, usually defined by official standards. It is closely related to integration but is more sophisticated in that it relates to underlying system design around recognised standards, that helps to reduce the amount of custom development required to achieve integration.	Senaps aligns with best practice interoperability standards, supporting integration of multiple data streams and associated platforms and services, while minimising unnecessary custom development. APIs from the two IoT platforms and irrigation management system also align with best practice 'restful' interoperability principles. Future versions of the SIMPaCT digital twin would favour integrations with platforms that comply strongly with interoperability standards. The application of SIMPaCT to new contexts will undoubtedly involve new integrations. High interoperability will keep options as open as possible and ensure that future integrations can be achieved as cost-effectively as possible.
3. Portability	Portability refers to the ability to migrate data or applications between two platforms or cloud service providers. Portability can include raw or abstracted sensor data, in-system data such as user access records, or custom applications such as data processing modules developed for specific devices. A given platform or storage location may be supportive of portability. Portability matters: • when migrating some or all the archived data into a new platform or data base, due to a change of service provider • the organisation has a position on avoiding vendor lock-in.	The core of the SIMPaCT digital twin is the Senaps platform, which hosts the three advanced analytics models. While these models can in theory by migrated to other environments, their deep integration with Senaps makes this challenging. The association between Senaps, IoT platforms and the irrigation management platform is far looser. Senaps can easily be integrated with different platforms for future iterations of the SIMPaCT digital twin. Data portability from Senaps and from the analytics models hosted within it, is good. All telemetry, model outputs and system records can be migrated easily.
4. Hosting	Hosting refers to the ability of a platform or service to provide an environment that is able to host a diversity of sensing devices or discreet software modules.	Senaps is capable of hosting custom software such as the advanced analytics models used for soil moisture prediction and irrigation scheduling. These models can easily be managed and developed within Senaps. If new models or software modules need developing and integrating into existing workflows for future versions of SIMPaCT, Senaps is capable of hosting them.
5. Supportability	The supportability of a platform or service relates to how well it can be configured and adapted to fit with the broader context of an organisation, and with the more specific context of a	Senaps can support the creation of sandbox environments for *testing* of integrations and overall functionality. Senaps is highly *configurable* and *adaptable* for a variety of different contexts. For example, it can

Quality criteria	Description	Comment
	project or data use case. Supportability includes: • *Testability* - can we test it to check if it meets our needs? • *Configurability* and *adaptability* - does the platform or service have existing settings/options that can easily be adjusted to ensure that it fits into our specific context? • *Maintainability* - can the technical requirements of the new platform or service be maintained by the environment that we will be running it in (e.g., does it need certain data to function, and can we provide that data?)? How well does the platform or service fit within the broader policy or administrative environment of the organisation? Are potential hurdles to timely and effective setup, integration, or operation foreseeable?	accommodate major changes to the structure of incoming data streams, meaning that future versions of the digital twin can work with different types of sensing devices and different IoT platforms. This ensures flexibility to refine the technical approach and business model.
6. Security	Security refers to the ability of a system to detect and resist unwanted external interference or data access and applies at all levels of a technology stack. Notable areas of focus for platforms and services include: • *User access management*—the ability of a platform or service to control who accesses a system and assign different permissions to different groups (custom access privileges). This can include access control functionality (e.g., password management; captcha; two-factor authentication). • *Data encryption*—the ability of a system to encrypt data where it is stored or during transfer.	The Senaps platform (which hosts all three advanced analytics models) has well-developed commercial-grade user access management, data encryption and overall security. Senaps has proven industrial security capabilities in the mining, agricultural and transport sectors. LoRaWAN networks are secure by design, as authentication and encryption are mandatory features.
7. Auditability	Auditability refers to the ability of a platform or service to provide and maintain full traceability of user access and transactions. Each time a user accesses a platform and does	Senaps provides the user with daily emails which include past and issued irrigation schedules produced by the advanced analytics models, and the status of the sensing device network. These emails build an auditable record of overall system performance

Quality criteria	Description	Comment
	something it is possible to record who it was, what they did, and when they did it. 'Doing something' can be as simple as accessing data, or as intrusive as changing core settings or code (which should be admin users only). Additional auditability functionality includes the capacity for generating custom reports based upon such records. This can be vital to best practice security management, data management and data sharing. It can also support roll-back of system settings.	Further, the advanced analytics models produce log files and records of model runs and issued commands. The log files are stored as part of the model runs or as separate data streams in Senaps. The log files are used for detailed diagnostics and are only available to model developers and the Senaps administrator and need to be extracted on a case-by-case basis. The underlying source code of the models is managed using Git, and their deployment is semi-automated. Therefore, changes can be easily tracked, and previous versions can be restored.
8. Scalability	Scalability refers to the capacity of a platform or service to expand or contract its functional capacity to meet changing needs. Scaling can include: • the addition of more devices to the network • an increase in the amount of data collected (which may result from more devices, more sensors per device, more metadata, shorter reporting intervals, etc.) • an increase in the number of data users accessing a platform or system • an increase in data sharing, to a greater number of external end points • a step up in the relative importance of a data use case, potentially to serve more critical business requirements.	Senaps is capable of handling huge volumes of data, many orders of magnitude higher than what is currently handled for the SIMPaCT 1.0 pilot. The high interoperability of Senaps (e.g. standardised metadata schemas) supports good scalability. The way the irrigation adapter is used to decouple Senaps from the irrigation management platform is also a critical aspect of good scalability design. The approach allows Senaps to control any type of irrigation management platform for any size of park. It also allows for the control of multiple irrigation management platforms at one (and hence multiple sites). This means that the existing design of the system can easily support a multi-user and multi-site digital twin with minimal additional development.
9. Availability	Availability refers to the amount of time that a platform or service is available to users and able to perform its expected functions. It might be always available (near 100% or continuous availability) or less. It can be specified as average availability levels or 'downtime per year' *Availability Level Downtime Per Year*	High availability is not required for Senaps because it only needs to provide *daily* updates to the irrigation management system. Even intermittent downtime (moderate to poor availability) should not prevent it from delivering this outcome. As such, there is no concern about availability. The availability of different parts of the SIMPaCT digital twin vary. The availability of sensor data may be very low (due to intermittency and device dropout), even if the availability of Senaps and the models within it is higher. The design of the SIMPaCT

Quality criteria	Description	Comment
	99.999% 5 minutes 99.99% 50 m minutes 99.9% 8.76 hours 99% 3.65 days 95% 18.25 days 90% 36.5 days The availability time window, such as the availability of the platform or service during business hours only or more, also needs to be considered. The availability needs have repercussions for how routine maintenance of a platform or service is scheduled. Certain providers may have set policies that either meet or clash with the availability needs.	analytics system allows for lower data availability and does not pass this through to the irrigation system.
10. **Reliability**	Reliability refers to the ability of a platform or service to do its job effectively across a defined period. An unreliable system is one that is unable to fulfill the functions expected of it. For SIMPaCT, this function is the delivery of continuous fit-for-purpose irrigation scheduling. A system may be operational but delivering a poor quality of service, and thus be 'unreliable'. Reliability is distinct from availability. A system might be available while also running sub-optimally and thus unable to fulfill the functions expected of it. One easy way to distinguish between the two is to think of availability as '*quantity* of service' and reliability as '*quality* of service'.	The reliability of Senaps is heavily contingent upon the availability of soil moisture sensor data. Sensing devices regularly display intermittent connectivity and go offline for a variety of reasons relating to the inherent limitations of the technology, combined with the complexity of the deployment context. If insufficient data is available for an operational station for several days in a row, the optimisation of irrigation scheduling will reduce to the point of unreliability. SIMPACT 1.0 is not able to infer soil moisture telemetry for offline devices using data from other devices in the network, meaning that the reliability of the system (its ability to do its job) is heavily compromised by the reliability of devices and their communications. This indicates a major focus for future research and development of the system (see Section 2.6.3.1).
11. **Performance**	Performance refers to the ability of a platform or service to support a series of context-specific needs. These are: • response times (application loading; browser refresh times; etc.) • processing times (functions; calculations; imports; exports)	The SIMPaCT digital twin does not support high simultaneous user access, which removes most of the strain commonly associated with platform performance. Performance requirements for meeting required irrigation outcomes are relatively low and Senaps is more than capable of meeting them.

Quality criteria	Description	Comment
	• query and reporting times (initial loads and subsequent loads; large batch or real time data movement).	
12. Usability	Usability refers to how easy a platform or service is to use, including the overall look and feel of the interface and the user experience (UX) design.	The SIMPaCT digital twin comprises multiple integrated platforms, each with its own user dashboard. This includes a LoRaWAN dashboard, an IoT platform, a combined IoT platform and irrigation management system, and Senaps. To consolidate workflow tasks, the Park Now operational dashboard was developed, hosted through Senaps. Users also receive daily reports from Senaps via email. Most standard operations carried out by the place owner and irrigation contractors can be managed through the Park Now and irrigation management system interfaces.
13. Reporting	Reporting refers to the ability of a platform to produce a report or visualisation based upon a custom user query. More developed reporting capabilities might include: • a customisable metadata schema (the 'tags' that you search by) • customisable search functionality (e.g., user-defined time periods, rather than pre-sets) • compound queries; and customisable visualisations. It includes the ability to download search or visualisation outputs in a variety of formats.	Senaps incorporates detailed customisable and user-defined automated reporting on sensing device availability and system operations.
14. User support	User support refers to the collection of user-focused resources that may accompany a platform or service. This can include documentation such as user manuals and how-to guides; help and FAQ resources; user forums or knowledge exchanges; as well as more active support such as a phone hotline or online helpdesk.	The SIMPaCT pilot project produced extensive technical documentation and operational manuals designed to support users and the ongoing operation of the system. Ongoing operational support from core service providers incorporates active user support.
15. Training	Training refers to the training materials (e.g., manuals) and active support (training sessions) provided to platform	The SIMPaCT pilot project produced training materials and delivered a series of training sessions to staff and contractors tasked with the ongoing operation of the system.

Quality criteria	Description	Comment
	users. It tends to build upon user support materials.	

E THE SIMPACT VALUE PROPOSITION

SIMPaCT was designed to address the challenges of irrigation at Bicentennial Park. These challenges exist within a broader context of growing environmental pressures that affect the whole of Greater Sydney, as well as other cities, towns and regional areas across Australia.

The SIMPaCT pilot project at Bicentennial Park was built around four key value propositions that impact the resilience of Bicentennial Park and its users:

Mitigating urban heat	Managing green infrastructure
The optimisation of irrigation to support maximum potential cooling from green infrastructure.	*Well maintained and thriving green infrastructure assets, combined with operational efficiencies*
Improving water efficiency	**Maintaining public amenity**
Irrigation control informed by data and predictive modelling, that optimises irrigation delivery, avoiding waste while ensuring plant health and cooling outcomes.	*Maintaining cool, green places for public health and wellbeing through drought conditions*

Mitigating urban heat

The issue

In Australia, the Urban Heat Island (UHI) effect has been scientifically analysed since the 2010s. In large cities, average temperatures can be 1°C to 3°C higher than average rural temperatures (AdaptNSW, 2022).

In NSW, Western Sydney suburbs are facing serious UHI challenges (Garshasbi et al., 2020; Greater Sydney Commission, 2018a, 2020; NSW Department of Planning Industry and Environment, 2021; Osmond & Sharifi, 2017; Pfautsch & Rouillard, 2019a, 2019b, 2019c; Pfautsch & Rouillard, 2020; Santamouris et al., 2017; UNSW et al., 2017; WSROC, 2021). Air temperatures in Western Sydney suburbs can be 6-10°C hotter during extreme summer heat events compared to suburbs in Sydney's east (UNSW et al., 2017). The heat challenge in Western Sydney is mostly caused by Sydney's geography and weather patterns, such as hot westerly winds and lack of cooling sea breezes, and this is accelerated by rapid urbanisation and significant decrease in vegetation cover (WSROC, 2021; Morrison et al, 2022). Unfortunately, this has the potential to exacerbate the UHI effect and worsen the local impacts in Western Sydney as climate change intensifies over the next decades (WSROC, 2021). Urban heat is contributing to the cumulative stress in Western Sydney's local communities, economies, and ecosystems (Morrison et al, 2022).

Increased urban heat is expected to have a direct negative impact on the health and wellbeing of people. Extremely hot weather can lead to life-threatening heat-related illness such as heat stroke and heat exhaustion. Heat can also make existing illnesses worse, cause serious permanent injuries and in extreme cases result in death. Vulnerable people like the elderly and the young are at higher risk and heat can exacerbate existing chronic conditions (NSW Health, 2022).

An economic assessment of the UHI effects for the City of Melbourne in 2012 (AECOM, 2012) estimated that total economic cost to the community due to hot weather can reach approximately $1.8 billion and the UHI effect contributed approximately $300 million through impacts on health, transport, energy demand, GHG emission, anti-social behaviour and tree health and wildlife.

The solution

Urban parks and green spaces are one of the most important defences we have against rising temperatures in our cities. The importance of green infrastructure in mitigating UHI effect and its provision of essential ecosystem services in a city is widely acknowledged (Motazedian et al., 2020).

The Low Carbon Living Cooperative Research Centre (CRC) published urban cooling strategies in 2017 to mitigate UHI issues in major Australian cities (Osmond & Sharifi, 2017). In the strategies, urban fabric, urban land cover and urban metabolism were identified as the major factors to cause UHI effects, and introduction of cool and permeable paving technologies, water and increased vegetation were encouraged for mitigation, which could reduce the average peak ambient temperature by up to 2.5°C. UNSW, Sydney Water & Low Carbon Living CRC (2017) also published a strategic study on the role of water in mitigating urban heat in Western Sydney to assess the cooling potential of multiple mitigation technologies and evaluated their impacts on energy, peak electricity demand, health, environment and thermal comfort. Modelling by Garshasbi et al. (2020) concluded that heat mitigation with cool materials, greenery, and irrigation will lower the peak and average daily temperatures respectively by 2.2 °C and 1.6 °C.

A number of public and private initiatives have been started in NSW to mitigate and manage heat impacts. In 2018, the Greater Sydney Regional Plan included mitigation of UHI and reduction of vulnerability to extreme heat as objectives to create a resilient city (Greater Sydney Commission, 2018a). To enhance green infrastructure, the NSW government developed the concept of the *Sydney Green Grid,* that is a network of high-quality green and blue infrastructure (Tyrrellstudio, 2017), and launched *Greening our City* to increase the tree canopy and green cover across Greater Sydney by planting one million trees by end of 2022 and five million trees by 2030 (NSW Department of Planning and Environment, 2022a). In *Nature Positive Sydney*, the Committee for Sydney highlighted the significance of living infrastructure in dense urban areas, with the benefits including its cooling potential and air quality improvement, thus reducing heat stress on vulnerable populations. (Committee for Sydney, 2023).

Both State and local governments have planning strategies and controls that prioritise mitigation of urban heat, maintaining cool environments, and retention and increase of tree canopy coverage in Western Sydney. The Western City District Plan (Greater Sydney Commission, 2018b) extends responsibility for these matters to Councils, other planning authorities and State agencies. Western Sydney councils (including Blacktown, Cumberland, Hawkesbury City, Liverpool City and Parramatta) have launched cooling strategies and introduced multiple measures to reduce the urban heat challenges, including amendments to local planning provisions to plan and design cool outdoor spaces and sustainable water supply (WSROC, 2021). As examples of concerned western Sydney Councils, City of Parramatta emphasises tree coverage and City of Penrith has recently introduced an Urban Heat Planning Controls Package (Penrith City Council, 2022). In the Aerotropolis Precinct the Western Sydney Aerotropolis Development Control Plan 2022 (NSW Department of Planning and Environment, 2022b) additionally addresses Smart Places.

The science

Cooling potential of green infrastructure

Plants keep urban environments cool in two main ways:

- Evapotranspiration. Where heat is transferred and dispersed into the air via the evapotranspiration of water through plant leaves. When optimised, plants can generate a net cooling effect that exceeds the rate of heat loss that might otherwise occur through standard evaporation.
- Shade. Where plants prevent direct solar exposure of solid surfaces with thermal mass (e.g. concrete, asphalt, hard ground), avoiding the accumulation of surface heat.

Plants, especially trees with large dense crowns, lower surface and air temperatures. Trees with large, dense crowns result in a big shade footprint keeping surface temperatures low. Large, dense tree crowns also transpire more water and are in contact with a larger volume of ambient air which leads to greater cooling due to evaporation from leaf surfaces. Wind will distribute the cooled air into the surrounding environment, effectively extending the cooling effect from transpiration far beyond the tree crown itself. Furthermore, the much-reduced flow of heat from surfaces shaded by tree crowns results in little or no additional warming of the ambient air. The reduction of heat flow due to surface shading and increased evaporative cooling from transpiration are the two key mechanisms that make urban trees the most effective plants for mitigation of urban heat.

Turf, shrubs and small trees on the other hand will have lower surface temperatures compared to hardscapes like concrete and asphalt, yet their capacity to lower surrounding surface and air temperatures is limited. Shrubs and small trees generally have a very small shade footprint which limits the area where surface temperatures are reduced to blocking solar radiation reaching the ground. Moreover, shrubs and small trees have low transpiration rates which limits their contribution cooling due to evaporation from leaf surfaces.

Maximising the cooling effect of green infrastructure by maintaining optimal plant hydration

The initial response of most plants to low soil moisture availability is a reduction or near complete closure of their leaf pores. This response will decrease water loss from transpiration and protect the plant from dehydration. At the same time, a reduction in transpiration means that evaporative cooling is reduced and the air surrounding the leaf is not cooled any more. Hence, evaporative cooling from plants will cease when soil moisture is limited. If water limitation persists, plants will initiate shedding of leaves which, in the case of trees, will reduce the density of the crown and thus reduce shading. Consequently, a limitation of plant-available water will result in warming of ambient air due to the loss of transpiration cooling and increased warm surfaces.

The opposite effect is gained when plants are optimally hydrated. Under such conditions, transpiration is maximised which leads to the largest possible evaporative cooling. Also, the plant will maintain the largest possible leaf area. For trees (and shrubs) this means their leaf area will be large, and crowns will be dense and expanding. The result is effective blocking of solar radiation, and an expanding shade footprint. Optimal plant hydration will result in maximum cooling effects of surface and air temperatures.

The SIMPaCT answer

A key goal of SIMPaCT is to create urban cooling via vegetation transpiration. By modelling the water requirements for an area in detail, SIMPaCT can maximise the Park Cool Island (PCI) Effect, (a counter to the Urban Heat Island), by delivering precisely enough water for optimal plant health and maximum potential evapotranspiration across all areas of the park, relative to current and forecast environmental conditions. Designing a system capable of delivering a measurable increase in cooling was a primary aim for the SIMPaCT pilot project.

During hotter weather standard irrigation scheduling may not always be enough to maintain optimal plant health or support maximum potential evapotranspiration. As such, the maximum cooling effect of an irrigated park during hot weather has often not been realised

Maintaining plant species that are optimal for creating a cooling effect

Certain plant species are better than others for supporting cooling (either through their quality and quantity of shade or their rates of transpiration). High-performing, 'cooling' species are not always prioritised by landowners. This can be the consequence of missing knowledge about a species' cooling potential or the lack of water for optimal hydration. Landowners tend to plant the hardiest species that require low or zero ongoing maintenance, a selection widely encouraged by experts and authorities following too many major droughts. However, these species will grow slowly, produce an open canopy and deliver little transpiration cooling. The SIMPaCT digital twin supports planting and maintenance of species that would otherwise not be planted. Thus, a wider application of SIMPaCT supports a shift in planting regimes that address urban cooling as an explicit aim.

Community benefit

As a result of implementing SIMPaCT, residents, workers and visitors will have a cool refuge during warm and hot summers and an attractive park they can enjoy all year round.

Improving water efficiency

The issue

Climate change impacts, urbanisation, and growing populations create competition for water, increase water quality issues and issues around water security (Romano & Akhmouch, 2019). These factors, complex and intertwined, are expected to give rise to new risks and uncertainties (Bai et al., 2016). In Australia, the urban water sector faces difficulties in providing secure, reliable, and affordable services in cities. Population growth, increasing densification, and climate change impacts are some growing areas of concern. Climate change impacts amplify the issues of population growth and increasing urban densification. Warmer temperatures and urban density create liveability problems.

Extended drought has been identified as a contributor to UHI. This has led to the need for increasing irrigation of urban green spaces in arid and semi-arid regions, in particular to reduce the thermal stress of urban population and mortality of urban fauna and flora (Livesley et al., 2021). The capture, storage, and treatment of alternative water sources (stormwater, roof water, and recycled sewage water) has provided new sources for irrigation that might be a pathway for alleviating urban heat and water stress. Irrigation as a heat mitigation strategy is relevant to urban areas including those in low rainfall, arid environments (Livesley et al., 2021).

As Sydney grows the need to meet increasing water demands become more complex when intertwined with increasingly dynamic climatic conditions. Sydney Water is faced by a confluence of challenges associated with peak water demands during heat periods, a warming climate, and a growing Western Sydney region. Sydney Water has an imperative to ensure per capita demand for water continues to reduce. There are no new water resource options for Sydney so as the city expands the cost to supply increased water needs will increase. As a result, it will increasingly become more financially attractive to use water efficiently, at all times.

Regionally, that is beyond the boundaries of the two large, coastal state-owed water utilities in NSW, the water supply costs during periods of water scarcity tend to escalate more rapidly and severely, meanwhile community desire for usable sports fields, healthy, green parks and respite from heatwaves is no less important than in Western Sydney.

Urban green infrastructure supports more resilient communities through increased amenity and cooling capacity but creates a demand for water to maintain it. This demand is expected to increase over the coming decades as the amount of irrigated green space increases and the impacts of climate change worsen. To support this increasing water demand, against a backdrop of increasing water cost and scarcity, new approaches to water efficient irrigation must be developed.

The solution

The efficient use of water for irrigation is critical during periods of water scarcity to ensure that available water is used to support the greatest possible positive impact including the ability of a park to create a significant cooling effect during hot weather. It may mean the difference between maintaining a sports field in a useable condition or allowing turf to die and closing the field, or between keeping mature trees alive or losing them.

There is a political driver to irrigate efficiently because historically during periods of drought-induced water stress, restricting outdoor water use has presented the greatest, lowest cost way to rapidly reduce water demand, often forcing the shutoff of publicly maintained irrigation systems leading to damage and loss of green infrastructure. Water authorities may allow special dispensation to maintain public amenity. This is often contentious but more readily supported when the irrigation system uses water efficiently. Indeed, such optimisation may come to be a pre-requisite condition for dispensation, and a foundation of a social license to operate irrigation during water restrictions.

Additionally, the other main driver for water efficiency of irrigation systems is to reduce water supply costs for the land owner. Whether using recycled or potable water, and regardless of environmental conditions, minimising costs is a full-time driver for optimising water consumption.

The SIMPaCT answer

SIMPaCT directly improves the water efficiency of an irrigation system by delivering precisely the amount of water required for optimal plant health in a given 'station' (an operational area defined by a relatively uniform vegetation type, soil type, slope and aspect). This precision is made possible through the accurate modelling of soil moisture on a per-station basis, combined with a seven-day weather forecast that prevents unnecessary irrigation ahead of rain events. Real-time data from soil moisture sensors acts as an empirical cross-check, allowing the system to adjust its scheduling to fine tune upcoming water delivery.

By responding to the actual water requirements at a detailed level, SIMPaCT is expected to operate an irrigation system using less water than a standard irrigation control system

Resulting outcomes

Regular irrigation during drought conditions also helps to ensure water availability, and maximum possible evapotranspiration that a plant can deliver, by preventing the drying out of the soil surface and maintaining permeability. This ensures that each irrigation event results in increased soil moisture that is accessible by plants, rather than simply running off into drains or evaporating from the surface. SIMPaCT helps to ensure reliable and regular irrigation occurs.

Through comparison of soil moisture data with irrigation system reports, SIMPaCT is able to detect faults and leaks in the standard operation of an irrigation system that might otherwise go unnoticed.

Smart place-based management of multiple water resources

The functionality that controls irrigation schedules can also be applied to automatically choosing the water source in cases where switching between stormwater reserves, river, bore water or recycled water, and potable supply within a precinct or park is available. This is the case faced in some regional areas where potable supply is backed up by river or more expensive recycled water. Automated decision making could factor in a constrained recycled water budget, operating within low cost energy pumping periods, or to avoid peak competing demands from the same water source, to dynamically adjust irrigation schedules while always ensuring plant health.

Operational benefits

Operational benefits for the land owner are to efficiently and effectively manage irrigation water demands and reduce precinct water consumption.

There is potential for the water authority to better coordinate peak water demands and peak irrigation demands with resulting water and energy and cost savings.

Managing green infrastructure

The issue

Place owners such as SOPA often manage large UGI assets. These assets deliver considerable value for public amenity and urban cooling, and for their positive contribution to urban ecology. Active irrigation is often required to ensure that this value is maintained. There are three key challenges with the management of UGI using active irrigation.

Firstly, poor or sub-optimal management of an irrigation system can result in damage to or loss of plants, and a resulting loss of the value that they provide (notably, reduced urban cooling and public amenity). Place owners experience a financial burden from plant damage and loss. This burden is direct (associated with the replacement of plants and rehabilitation of the landscape) and indirect (associated with reduced amenity, which can reduce income related to rental rates and the ability to hire out venues in the location).

Secondly, poor or sub-optimal management of an irrigation system can equate to poor water efficiency, resulting in over-watering of certain areas. This can include delivery of more water than a location requires during dry conditions, or the unnecessary delivery of irrigation prior to rainfall. Undetected faults in the irrigation system (e.g. leaks and damaged hardware) can lead to failure to deliver the irrigation water.

Finally, the operational costs of UGI management can be substantial, particularly where irrigation systems have manual input and labour costs are high. Sustaining operations to ensure the ongoing health and maximum potential value delivery of UGI can be a significant financial burden, and may be a disincentive for the expansion of green infrastructure for some place owners.

The SIMPaCT answer

SIMPaCT can improve the management of large green infrastructure assets through the use of live data and the optimisation and automation of an existing irrigation system. There are three main management benefits.

Firstly, SIMPaCT captures real-time data about soil moisture from an extensive network of smart low-cost sensing devices deployed throughout the precinct. This sensor data, combined with data from the irrigation system, can be used to check the current functioning of the irrigation system and detect leaks and faults that would otherwise go undetected.

Secondly, SIMPaCT can ensure that all areas of the precinct are irrigated optimally, in accordance with their particular needs and weather forecasts, enabling the precinct to deliver maximum benefit for amenity and cooling while optimising water efficiency and keeping the costs of water supply to a minimum.

Finally, increased automation of the irrigation system can potentially reduce labour demand. While this may not translate directly into reduced operational costs in real terms, it may free up contractors to spend more time on tasks that they previously had little time for, improving overall management outcomes.

Wider benefits

Knowledge transfer from SIMPaCT leads to improvements in irrigation management of public green space and associated human thermal comfort and community benefits.

Through SIMPaCT, SOPA will rapidly grow its capacity to operate smart urban green infrastructure specifically, and smart city technology more broadly, whereby it will strengthen its position as leader in sustainable and climate responsive urban design.

Maintaining public amenity

The issue

The NSW government has acknowledged high-quality urban green infrastructure as a major contributor to public amenity, which promotes public health and increases the climate resilience of cities (Premier’s Priorities 10 and 12). Since 2019, the NSW Government has invested more than $30 million to improve and expand UGI across Greater Sydney. As urban density increases and there are smaller and fewer private outdoor spaces and gardens, public parks become more necessary for recreation, connection to the natural environment, and respite. Outcomes from access to healthy green spaces and sports fields are physical and mental health, and community wellbeing. Public parks are increasingly being used as a venue for public and private events. The value of usable, healthy, cool UGI increases.

The solution

In order to maintain high-quality UGI and ensure that it delivers ongoing public amenity, many local governments across NSW need to use active irrigation systems. Thus, it is responsible and timely for NSW to develop optimised irrigation strategies that help reduce water use while still maintaining healthy green infrastructure, maintaining public amenity and supporting climate resilience.

The SIMPaCT answer

SIMPaCT can directly improve the maintenance of public amenity in parks through the optimisation of UGI management at a detailed level.. As well as the practical benefit of ensuring the efficient use of limited water for the purpose of maintaining public amenity, the optimisation of water efficient irrigation also supports a social license to maintain UGI assets during droughts for their public amenity value, when efficiency is a prerequisite for irrigation.

The SIMPaCT data model contains metadata for the presentation standard and water requirement of operational ‘stations’ within the park. During a period of restricted water supply, the supply of water to each station can be prioritised (or de-prioritised) based upon this metadata. This means that areas with the highest public amenity value can be kept healthy and usable, at the expense of less used or less visible areas. Due to this information being embedded within the system, a ‘public amenity preservation’ mode can be created as an automated and comprehensive setting within SIMPaCT. This would reduce the risk of damage to areas with high public amenity value and ensure that no water is ‘wasted’ on areas that are a lower priority. It also mitigates against the loss of tacit knowledge via staff or contractor turnover.

Additional potential value propositions

In addition to the four key value propositions, SIMPaCT offers additional benefits.

Energy efficiency: water pumping and water treatment use energy. The demand for irrigation often peaks at times of heat, when there is peak energy demand on the electrical grid for cooling buildings. Because SIMPaCT can optimise irrigation scheduling, water consumption can be spread over a longer time frame to smooth the peaks, or shifted to times when energy demand is lower and energy is less expensive.

Biodiversity: plants provide habitat, food and protection for wildlife. The SIMPaCT focus on maintaining the health of plants will help to sustain conditions for enhancing biodiversity. Linked healthy parklands create wildlife corridors, which are important for providing the scale of habitat required for some species.


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