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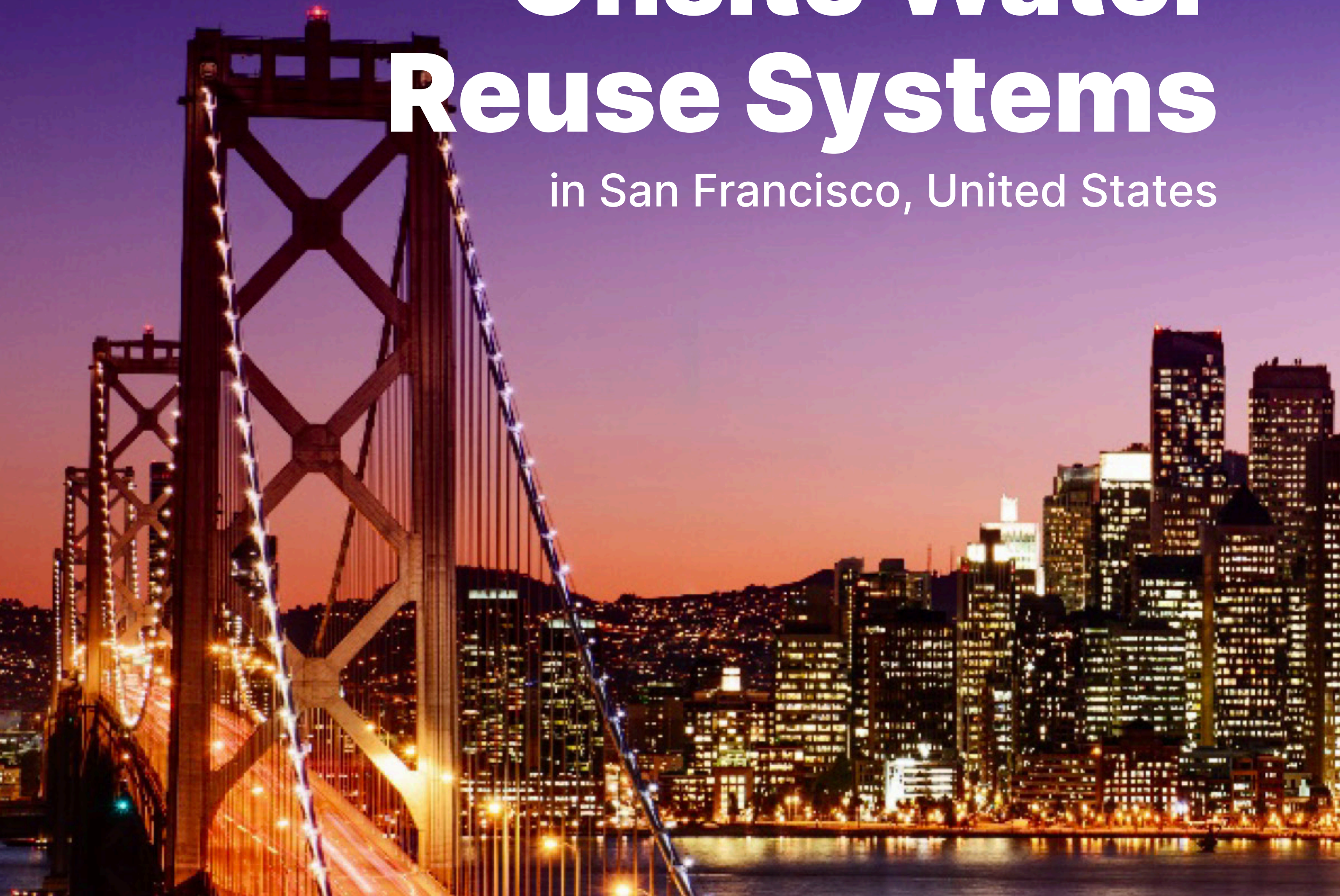
Onsite Water Reuse Systems

in San Francisco, United States



San Francisco is spearheading the city-wide installation of onsite non-potable water reuse systems (ONWS). Through a city ordinance, local authorities have induced a quickly growing ONWS market and initiated stakeholder networks that support the diffusion of ONWS solutions in San Francisco and beyond.

Since 2012, the city has introduced and further developed the Onsite Water Reuse Program, which today enforces ONWS in commercial, mixed-use and residential buildings larger than 9290m2 (100,000 ft2) gross floor area. By Noember 2022, 48 ONWS were operational and a total of 119 systems were listed in the permitting pipeline.

Collection & Transport
There are in-house collection, storage and (re-)distribution systems for non-potable water reuse. Treated water is distributed within buildings through purple pipes with specific signage. Buildings are connected to the city water supply and sewer network in the event of system failure.

Treatment
A variety of combined treatment steps ensure compliance with local regulatory requirements. These include biological processes, membrane filtration, and disinfection. Online monitoring systems are increasingly applied to ensure safe and reliable operation.

Products
Recycled water is collected for indoor non-potable uses (toilet flushing, irrigation, clothes washing, or cooling towers), and outdoor uses (irrigation, decorative fountains, dust control, or cooling). Heat recovery from wastewater streams is increasingly encouraged.

Benefits
Reduced dependence on a centralised water supply, decreased infrastructure costs, enhanced flexibility and resilience of the water infrastructure, and increasing the sustainability ratings of buildings.

Lighthouse Synthesis Report

Introduction

San Francisco (SF) is a densely populated major economic hub in Northern California with high economic dynamism and fast population growth [8]. SF used to have a non-diversified water supply system, which heavily relied on the long-distance transfer of surface freshwater [15]. Since the end of the 20th century, increasing water consumption [2] and repeated droughts have resulted in water stress, forcing local authorities to explore alternative water sources [3]. From the 1990s onwards, recycled wastewater increasingly became a potential alternative water source. San Francisco's Public Work Code (Article 22) was amended to define recycled water use areas within the city and as part of the preparations for a 'Recycled Water Master Plan'. In response, the Public Utilities Commission (SFPUC) started exploring the potential of centralised non-potable water reuse [15].

Until the mid-2000s, centralised water reuse was seen as the most viable solution to increase local water resilience. However, this solution proved hard to implement as SF's hilly topography, coupled with long distances between treatment plants and users, required pumping reclaimed water, which increased energy and distribution costs [7, 10]. Many buildings that had installed purple pipes thus never received recycled water and the city adapted its strategy to supplying large irrigated areas like parks and golf courses with centrally recycled wastewater [10]. In the early 2000s, onsite water reuse systems (ONWS) were increasingly discussed as an alternative way for reducing new building's water use [7, 13]. At the same time, several real estate developers approached the local utility, (SFPUC), and expressed interest in implementing ONWS in their buildings in order to obtain the highest level building sustainability certification from the LEED programme [4].[1]

SFPUC thus became interested in promoting the concept of ONWS and established an ONWS demonstrations plant in its new headquarters' building. In September 2012, the city adopted the Onsite Water Reuse Program and added Article 12C to the SF Health Code. The ordinance allowed for the collection, treatment and use of alternative onsite water sources for defined non-potable uses. Initially, the ONWS program was implemented on a voluntary basis, which enabled SFPUC to determine the feasibility of mandating such a program. In 2015, Article 12C became mandatory for new construction projects with more than 23,225m2 (250,000 ft2) of gross floor area. The article has since undergone further amendments. Since 2021, all new commercial, mixed-use and residential buildings with a gross floor area larger than 9290 m2 (100,000 ft2) have to install and operate an ONWS at the building or district scale.

ONWS can capture, treat and reuse blackwater (wastewater from toilets), greywater (wastewater from the laundry, kitchen/bath sink, and shower), rainwater, stormwater, air conditioning condensate, and foundation drainage. There is no one-size-fits-all solution for designing ONWS, and technological solutions differ substantively between different building types and sizes. Yet, they all must adhere to the water quality requirements set by the city's regulative framework. After treatment, the recycled water can be used for indoor non-potable uses (toilet flushing, irrigation, laundry, or cooling towers), as well as for outdoor uses (irrigation, decorative fountains, dust control, or cooling). By Nov 2022, 48 ONWS systems were operational in the city and a total of 119 projects had submitted water budget calculations [16[2]]. SF has thrived as a leader in using ONWS, receiving several awards for its innovative approaches to water recycling. The city has also become a national and global reference point – or 'lighthouse' - for other cities looking to adopt ONWS systems. In addition to its own efforts, SFPUC chairs the National Blue Ribbon Commission (NBRC) that works to promote the use of ONWS across North America.

The city's success in becoming a leader in ONWS adoption is rooted in a long-term, iterative and distributed learning process. In this brief, we will examine the key drivers and challenges the city has encountered on the way to implementing ONWS. This discussion will be structured

1 LEED (Leadership in Energy and Environmental Design) is a globally used green building rating system. Its certificates are a recognized symbol of a building's sustainability achievement.

2 Submitting a water budget to SFPUC indicates that the project is in the pipeline for eventually installing an ONWS and will be counted as such in SFPUC's tracking and reporting systems.

around the five key analytical dimensions of the Lighthouse project's analytical framework. By examining these dimensions, we hope to gain a better understanding of the key factors that have led to the successful implementation of ONWS in SF, and to identify recomendations for other cities that seek to adopt similar urban water management solutions.

System-Set Up: Technology Description

As outlined above, a wide variety of ONWS designs have been implemented in the city. At a generic level, the typical ONWS solution includes: a collection system for different types of source water, an equalisation tank, a treatment system, a treated water storage tank, and a non-potable water distribution system [22] Treated water is redistributed within the buildings through separate purple pipes with specific signage. Connection to the city's water supply network is required, as is a connection to the sewer network. This way, onsite treatment plants can automatically divert into bypass mode in the case of a system failure or prolonged maintenance [14].

The choice of the exact treatment steps depends on the water sources and reuse purposes ("fit-for-purpose"). Treatment of blackwater and greywater typically comprises a specific combination of primary pre-treatment, secondary biological treatment (activated sludge processes, often membrane bioreactors), and various tertiary treatment steps, such as microfiltration (MF), ultrafiltration (UF), ultraviolet light (UV) disinfection, ozone disinfection, and/or chlorination (Figure 1) [22]. In response to the local regulatory framework, treatment must comply with mandated log10 reduction targets (LRTs), which represent the minimum inactivation requirements of pathogens (viruses, protozoa, and bacteria). Technology providers increasingly develop standardised self-contained treatment systems with most of the plumbing and electrical work already completed. These turnkey solutions reduce installation timelines, saving time and money [23]. Lastly, developers have to install remote monitoring systems to ensure reliable and safe operation of their ONWS. This includes remote control units, automated alarms and diversion systems, backflow prevention devices, and air gaps [11, 22].

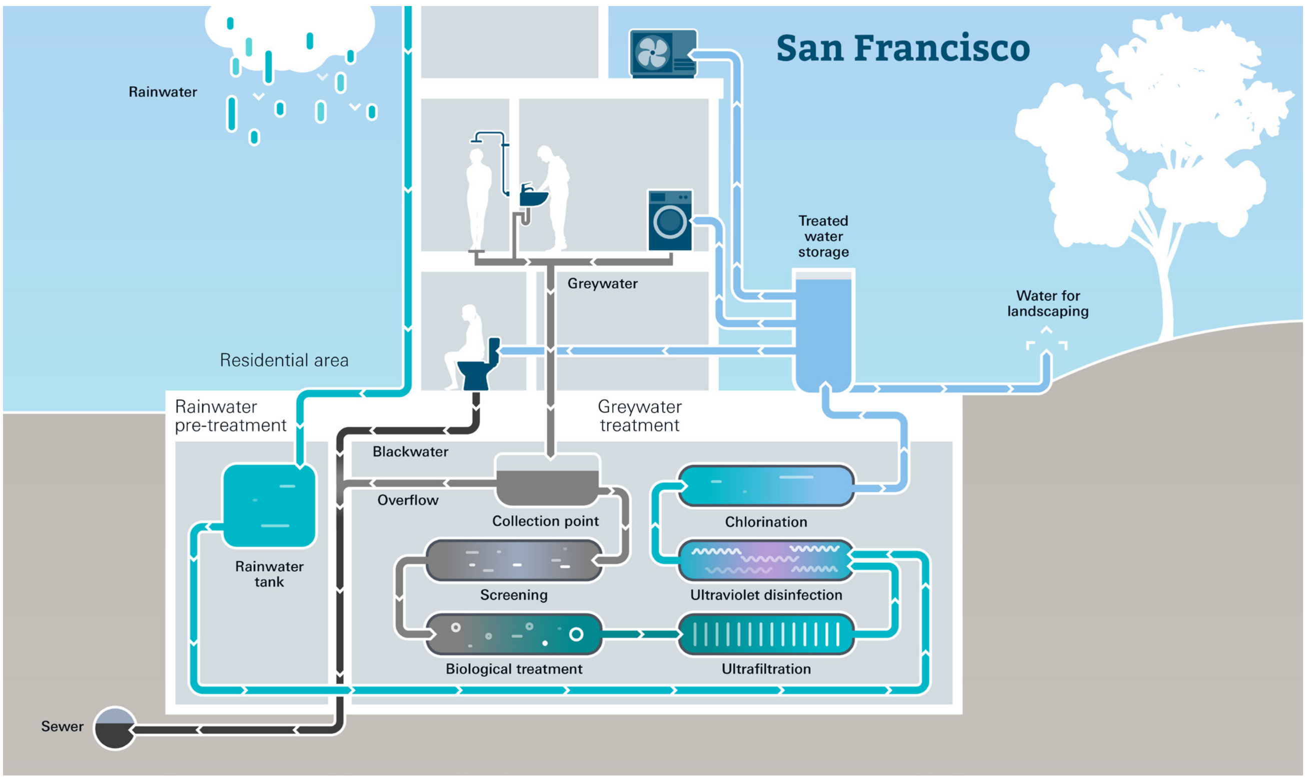


Figure 1: Schematic overview of a typical onsite treatment system, using membrane bioreactor technology for greywater reuse (Own illustration based on [15, p. 55]).

Institutional Framework Conditions

Legal & Regulatory Conditions

When SF started installing its first ONWS systems, onsite water reuse was not common practice in US cities nor globally. Templates for effective regulations and governance arrangements were thus widely lacking. To develop a local programme and permitting process for decentralised water reuse systems, SFPUC had to coordinate among different city departments[3] in an experimental, bottom-up process 'from scratch'. In a series of intense exchanges, SFPUC, regulators, and several city departments iteratively drafted a novel city ordinance introducing a regulatory framework for installing and permitting ONWS [4]. They added Article 12C to the city's health code (the Non-Potable Water Ordinance) and established SF's Onsite Water Reuse System Program that outlines a ten-step process to review, permit and monitor ONWS systems (Figure 2). For each step, it defines the key actors, their roles and responsibilities, the information required from developers and the necessary operation & maintenance (O&M) protocols [22].

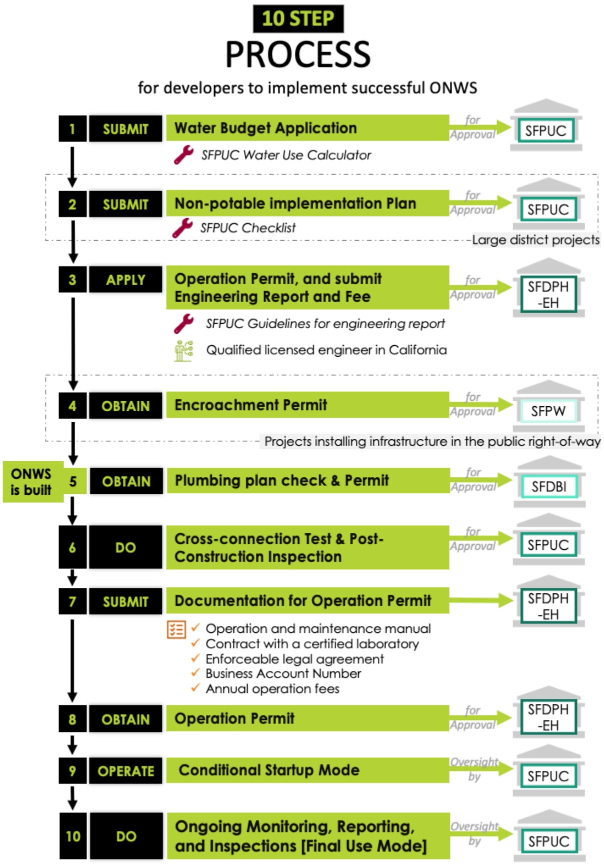


Figure 2: Ten step permitting process for ONWS. (Own elaboration, based on [23])

This work made SF a global pioneer in defining a comprehensive governance arrangement for ONWS that covered the full project cycle, from planning to installation and O&M [22]. However, the initial version of Article 12C and the ONWS program contained many open issues. Specifically, the need for regular effluent water quality testing in onsite plants with grab samples [25] made ONWS prohibitively expensive.

Accordingly, the National Water Research Institute (NWRI) and SFPUC jointly organised an expert panel, including regulators, technology firms, academics, and consultants, which was tasked to develop a regulatory water quality framework tailor-made for ONWS systems. The goal was to ensure public health while simplifying ONWS's design, installation and O&M processes and reducing water quality monitoring costs [3]. This key innovation, the 'Risk-Based Framework', listed LRTs for different water sources and end uses [24]. Its basic idea follows Australian regulatory approaches: instead of focusing on continuously measuring the effluent quality, it defines critical control points in ONWS systems that indicate whether each treatment step is adequately operating. If each step works as expected, the reuse water quality can be assumed to meet the defined quality criteria [24]. If online monitoring systems identify issues with a treatment step, the system automatically switches into bypass mode until they are resolved.

Once the Risk-Based Framework was established, local stakeholders also worked toward a regulatory amendment that would mainstream these water quality standards across the state [3]. Approved in September 2018, it is anticipated that the state water board will amend the California Water Code to adopt ONWS quality standards in line with the Framework by late 2023. Additionally, several other states (Colorado, Hawaii, Washington, and Minnesota) have developed legislation and/or policies to advance ONWS based on the Risk-Based Framework [9]. This novel Framework, thus, has played a key role in diffusing ONWS not only within SF, but also across California and other States in the US.

3 Public Health (SFDPH), Public Works (SFPW), and Building Inspection (SFDBI)

Contractual & Financial Arrangements

In general, the capital expenditures for installing ONWS plants and the OPEX for running them are covered by building owners, developers and/or the building tenants. The capital expenditures for the installation (CAPEX) and the operation (OPEX) of ONWS were initially rather high. Therefore, in 2012, SFPUC developed a grant programme to compensate for some of the CAPEX costs for buildings that voluntarily implement ONWS. These grants are up to $1,000,000 [14] and are still being offered. Their incentivising effect, however, has been limited because they apply only to voluntary applications of ONWS.

Another (small) economic incentive for installing ONWS was created in February 2017, when SFPUC adjusted the procedure for calculating water capacity charges. SFPUC calculates this capacity charge before a site permit is issued for new developments. Buildings with ONWS had to pay a decreased capacity charge, as they typically put a lower strain on the centralized freshwater and sewer systems. Buildings with ONWS furthermore also use less fresh water, which lowers their average water and sewer bills. In addition, also the increasing technical maturation and standardisation of ONWS products, firms and market structures are likely to further increase ONWS's economic viability through economies of scale. Although these interventions taken together can significantly reduce the payback period for ONWS systems, whether and how quickly a financial return on investment can be achieved by ONWS remains a key discussion point especially among building owners and developers. SFPUC and other local stakeholders keep streamlining and amending the ONWS program to address this point.

Industry & Market Structures

Initially, the lack of local suppliers for high-quality onsite treatment plants and related services made designing and installing ONWS cumbersome and expensive [12]. Since real estate developers had difficulties in finding specialised planners and suppliers, many consulted external national or international firms. Only when the ONWS market started booming, did local start-ups emerge and start supplying innovative ONWS systems.

A critical development in improving the (niche) market for ONWS was the emergence of design-build-operate business models (DBO). In DBOs, the same company designs, plans, implements, and operates the ONWS for a set period. This is beneficial for three reasons. First, the complex ONWS permitting process requires specialised knowledge at different stages. Getting a permit involves a combined effort of owners, architects, and structural, mechanical and electrical engineers, technology suppliers and operator firms. Having one firm responsible for the entire permitting process can be very conducive as it simplifies communication and coordination among all the parties involved in this complex process. Second, regulations define that an ONWS which treats blackwater has to be operated by a licensed "Class Two Wastewater Operator". Since finding certified wastewater operators for ONWS was (and still is) challenging, having the same firm design, plan and implement an ONWS also operate it strongly improved O&M quality. This arrangement is also conducive to interactive learning, since the operators can directly exchange experiences with the design team on certain technologies' performances and operational challenges in the field. Third, adopting a DBO model enhances the creation of a reliable, long-term income stream for the involved firms compared with directly handing over the projects to a third party after completion. DBOs, thus, entail strong incentives to design a system that is well-adapted to a building's performance needs, as well as increasing regulatory compliance, robustness, longevity, and, ultimately, economic viability [4].

As an additional measure to support local industry and market formation, SFPUC published guidebooks and a list of validated and accepted technologies, treatment processes and technology/service suppliers that provide state-of-the-art ONWS solutions [17, 20, 21]. Additionally, many ONWS suppliers and operators actively shared general information on treatment technologies and how to effectively implement them on their websites and at specialist conferences and workshops.

Knowledge, Skills & Capacities

SFPUC in many ways champions knowledge, skill and capacity development around ONWS in SF. It organises public outreach activities, expert meetings, workshops and conferences to discuss onsite water reuse with local communities. Publicly accessible guidelines complement these activities, such as SFPUC's Onsite Water Reuse Program Guidebook [22]. This – and many similar - publications aim at improving local stakeholder's capacity to assess alternative water sources and estimate non-potable water demand. They also provide practitioners with examples of how to design treatment systems that meet the LRTs required by the Risk-Based Framework. Furthermore, the technological skills of project planners and suppliers are continuously increased through learning-by-doing processes. More and more firms with strong technological capabilities have entered the ONWS market both within and beyond California, as they sense an increasing demand for these novel solutions.

While SFPUC led its development, the ONWS program is the collaborative result of a broad transdisciplinary stakeholder network [27]. This included key contributions from local sustainability consultants, technology suppliers, universities, NGOs and operator firms. Sustainability consultants and NGOs in particular have made continual efforts to increase the technological knowledge and capacity of local planners, developers, and property owners. For example, the WJW Foundation issued the "Non-potable Water Reuse Practice Guide", which offers straightforward explanations of why and when to consider ONWS in a user-friendly way [28]. Local universities have also developed technical and scientific knowledge around ONWS (cf. e.g. [1, 5-7]).

To further increase technical capacity, especially of operators, the NBRC is working with the Water Environment Federation, Water Professional International, and WateReuse Association to develop tailor-made education and training. Ultimately, the target is to establish a comprehensive training and certificate programme for ONWS operators, which is expected to become available in 2023.

Recognition & Legitimacy

The ONWS program profited both from conducive context conditions in SF and strategic activities by local actors that increased its legitimacy. Droughts, climate change and economic expansion have intensified the city's search for feasible and resilient solutions to water shortages, thus, boosting the ONWS programme's legitimacy. With SFPUC, a local champion furthermore existed, that played a key role in coordinating stakeholders and different city departments, in developing the ONWS permitting process and issuing the novel city ordinance. SFPUC was in a unique position to do so because it manages water, wastewater and energy under one roof. The innovative attitude and openness for collaboration among city departments, regulators and other key stakeholders arguably have been another key factor in the city's success story concerning ONWS.

The strategic activities of local stakeholders were also critical for legitimising ONWS. For instance, installing the Living Machine project at SFPUC's headquarter helped create the credibility of ONWS within the utility and among key stakeholders and the wider public. The Living Machine™ is a constructed wetland system, consisting of primary treatment, tidal and vertical flow wetlands, and disinfection stages. It was designed to treat about 18,927 litres (5,000 gallons) per day of (combined) wastewater for toilet and urinal flushing, reducing SFPUC's potable water demand by 65% [22]. The project's scale proved the water-saving potential of ONWS [18]. Its nature-based treatment steps were furthermore installed at a publicly accessible location. This was instrumental in building public acceptance and normalising the idea of onsite water reuse. Guided tours for the public increased education and awareness of ONWS among city residents [3]. The system is now being updated to get in sync with current LRT standards and includes an advanced treatment system that produces almost potable water quality for educational and outreach activities. The installation of ONWS in iconic high-rise buildings, such as 181 Fremont and the Salesforce tower, also improved the innovation's recognition and legitimacy locally.

In addition, SFPUC strategically fostered the development of a dense network of key stakeholders involved in designing, permitting, implementing and managing ONWS systems [26]. This network became instrumental in resolving development barriers, identifying opportunities and defining critical research needs [26]. Recognising the importance of iterative learning in programme development, SFPUC actively sought and incorporated feedback from a broad set of stakeholders as the ONWS program progressed. This interactive and reflexive approach helped to distribute ownership across different stakeholders, thus, increasing the ONWS program's legitimacy. SFPUC was also one of the main actors behind establishing the NBRC, which played a crucial role in diffusing ONWS beyond SF through lobbying of State and National governments, creating legitimacy for it beyond the local level [26].

As the recognition and legitimacy of ONWS grew and the number of successful projects increased in the mid-2010s, large tech companies in Silicon Valley, including Google, Facebook (Meta), and Microsoft, decided to adopt ONWS voluntarily in their new building projects. Mentioned often by interviewees, this development provided an additional boost of legitimacy for the ONWS program. At the same time, some legitimacy challenges remain. For instance, regulative frameworks for ONWS still differ from place to place and between States, creating strong diffusion barriers [9]. OPEX costs are also relatively high. While these costs can be borne easily in many new developments in SF, other communities might struggle with raising the money needed to operate and maintain ONWS. The long payback period for ONWS also makes it difficult for investors to recover their initial investments, hindering market diffusion [10]. Some interviewees questioned whether the energy and resources required to operate and maintain ONWS systems outweigh their benefits in all cases. To address these challenges, full lifecycle assessments, including a holistic view of ONWS costs and (economic, social and ecological) benefits, are needed. In this regard, the Environmental Protection Agency (EPA) has taken steps towards developing a comprehensive assessment tool called the Non-Potable Environmental and Economic Water Reuse (NEWR) Calculator[4]. While it does not conduct a full lifecycle analysis, the Calculator is a valuable tool for comprehensively assessing onsite water solutions' environmental and economic impacts.

Key Interventions & Lessons Learnt

As described above, ONWS have been successfully diffused and are increasingly taken for granted in SF. Multiple key interventions of local actors over the past decade have enabled this outcome. Particularly, the detailed and comprehensive permitting process and regulative framework developed in the city are globally unique and a key element in qualifying SF as a "lighthouse case". Based on our analysis, four key interventions proved critical in creating this success case.

First, continued political support and SFPUC's long-term strategic commitment and perseverance in developing and adapting the ONWS program were an often mentioned critical success factor. Introducing the first comprehensive regulatory framework for installing, permitting and running ONWS became possible thanks only to a series of intense interdepartmental exchanges between SFPUC, local and state-level regulators, and several city departments. The collaborative, iterative and self-reflexive way in which the ONWS program and the city ordinance and regulative framework were developed and iteratively adapted thereafter proved highly effective. It brought key stakeholders on board, enabled broad knowledge exchange, as well as the development of local industry and market structures.

Second, extensive outreach and knowledge exchange activities were instrumental in establishing and improving the understanding and capacity of stakeholders to work with ONWS. Initially, there was a lack of knowledge about its potential and application options. Outreach activities by SFPUC and other local actors, thus, strategically targeted lay people, developers, planners, practitioners and regulators. SFPUC and local NGOs produced a series of reports and white papers (e.g. [14, 22, 28]) that provided straightforward explanations of why and how to consider ONWS. These activities also proved crucial in establishing and maintaining legitimacy.

4 https://www.epa.gov/water-research/non-potable-environmental-and-economic-water-reuse-newr-calculator

Third, the Risk-Based Framework is a key innovation developed by various actors in SF's ONWS program that eased and clarified regulative requirements for ONWS. It is increasingly being used as a template by other jurisdictions in the US and beyond because it provides clear guidelines for equipment suppliers, developers and practitioners when designing, constructing, operating, and maintaining these systems [19]. This pioneering regulative Framework, specifically tailored to the needs of ONWS, outlines how to ensure public health, while reducing water quality monitoring costs.

Fourth and finally, the development of DBO-business models among local technology suppliers has proven to be a key success factor. DBO business models enable an efficient permitting process and simplify the installation process for building owners, developers, and regulators. They also create a more long-term and reliable income stream for the technology suppliers and incentivises them to design well-adapted, robust, safe, and efficient onsite treatment systems with low O&M costs. This model in principle could be emulated in other cities opting for ONWS.

While the ONWS program in SF so far has been a success case, key challenges remain. These include the limited number of operators with the required expertise to operate such systems, which has been addressed by the above-mentioned certified training and exam programme for ONWS system operators. Another challenge is the high CAPEX and OPEX costs of ONWS. These limit fast returns on investments and hinder a fast market-based diffusion trajectory. ONWS in SF are furthermore mostly implemented in new, high-end real estate developments that can afford the high OPEX costs [10]. In many other communities, CAPEX and OPEX are likely to pose more significant barriers for diffusion. Finally, further economies of scale and learning curves both in the (mass-) manufacturing of treatment systems and O&M models (as well as innovative business models) are still needed to make ONWS a global solution to urban water challenges.

About the Lighthouse Project

Resource-oriented decentralised urban water management systems improve the flexibility, resilience and sustainability of water and sanitation infrastructure and are, thus, key in sustainability transitions. The Lighthouse Project assesses some of the most prominent examples.

Why? – Project Goals

Decentralised urban wastewater treatment and reuse systems (DUWTRS) will play a key role in enabling sustainability transitions in the water and sanitation sector. DUWTRS close loops, recover valuable resources, produce marketable products, reduce the energy and water demand and can quickly be adapted to changing conditions. Despite increasing evidence of their potential benefits in improving the flexibility, resilience and sustainability of water and sanitation infrastructure, only a few cities worldwide have successfully implemented "lighthouse initiatives" (LHs) at scale. Systematic evidence of critical success factors and how to best implement LHs in cities in developed and emerging economies are lacking.

The Lighthouse Project conceptualised what are LHs and selected representative projects to analyse. The objectives were: 1), to identify distinctive characteristics of LHs, 2) to identify cities and neighbourhoods that have established LHs and assess technological and institutional best practices, and 3) to synthesise the results and produce templates for the diffusion of ODUWMS in cities in developed and emerging contexts.

What? – Lighthouse Initiatives Key Characteristics

Comprehensive arrangement: Integrating new technologies into a matching socio-economic and institutional context
Long-term perspective (project length and available funding): Stable incentives that enable 'adaptive learning'
Broad-scale adoption: Fully developed value chain at neighbourhood/city district level comparable to a centralised approach
Visibility and impact beyond immediate context: Examples that can inspire/guide initiatives to replicate core features

How? – Research Logic & Methods

We adopted a cross-comparative case study approach that synthesised results from prior Eawag projects (4S and BARRIERS) and amended them with additional secondary data and targeted expert interviews. In doing so, we generated practice-oriented lessons on how to best implement LHs and derived new theoretical knowledge of their success to highlight sustainability transitions within the urban water and sanitation sector.

Now? – Recommendations

Create a local ONWS program with dedicated leadership.
Establishing a clear permitting system that clarifies roles and responsibilities is key to sustainable ONWS. A committed leader who actively coordinates among stakeholders, including city departments, utilities, regulators, real estate developers, technology suppliers, operators, academia, and community organisations is key.

Iteratively adapt policies and regulative frameworks.
Introducing perfect regulations from scratch is hardly possible. An iterative and self-reflexive approach to adapting regulatory frameworks, permitting pathways, financial incentives, performance standards, etc. is more realistic. Coordinated and collaborative learning-by-doing is thus vital. Key outputs from previous lighthouse initiatives (e.g. Risk-Based-Framework) can serve as templates that can be locally adapted.

Construct a well-connected stakeholder network.
ONWS are a systemic innovation that depend on coordinating stakeholders with different interests. Regular meetings are key to inducing knowledge exchange, market formation, legitimation and regulatory adaptations. Organising workshops, conferences or guided tours to demonstration plants are an effective measure.

Promote Design-Build-Operate (DBO) business models with long-term contractual arrangements.
Long-term contractual arrangements between technology suppliers and residents/building owners is conducive to efficient resource allocation. DBOs support effective navigation of permitting processes and incentivise robust and cost effective ONWS solutions and adequate O&M.

Engage in constant outreach, knowledge dissemination and training activities.
Increasing the knowledge and understanding of key stakeholders on ONWS' potential, functioning and challenges is vital. To this end, well-designed materials tailored to target groups are critical, particularly when developers, regulators and firms lack expertise in advanced ONWS technologies. Educational resources and certified trainings for ONWS planners, installers and operators are crucial components.

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References

1. Bintliff, J.M., Rainwater Harvesting in San Francisco Schools. 2011.

2. Dinar, A., et al., The Evolving Nature of California's Water Economy, in California Agriculture: Dimensions and Issues, J. Siebert, Editor. 2003.

3. Hacker, M.E. and C. Binz, Hybrid governance arrangements for urban infrastructure transitions: Comparing the emergence of onsite water reuse in San Francisco and New York City. under review.

4. Hacker, M.E. and C. Binz, Navigating institutional complexity in socio-technical transitions. Environmental Innovation and Societal Transitions, 2021. 40: p. 367-381.

5. Harris-Lovett, S.R., Decision Support for Multi-Benefit Urban Water Infrastructure. 2018: University of California, Berkeley.

6. Hendrickson, T.P., et al., Life-cycle energy use and greenhouse gas emissions of a building-scale wastewater treatment and nonpotable reuse system. Environmental science & technology, 2015. 49(17): p. 10303-10311.

7. Kavvada, O., et al., Assessing location and scale of urban nonpotable water reuse systems for life-cycle energy consumption and greenhouse gas emissions. Environmental science & technology, 2016. 50(24): p. 13184-13194.

8. Kavvada, O., K.L. Nelson, and A. Horvath, Spatial optimization for decentralized non-potable water reuse. Environmental Research Letters, 2018. 13(6): p. 064001.

9. Kehoe, P. and T. Nokhoudian, Pathway to scaling up onsite non-potable water systems, in Resilient water management strategies in urban settings: Innovations in decentralized water infrastructure systems. 2022, Springer. p. 119-148.

10. Koehn, J. How SF's Recycled Water Program Stumbled Into Performative Environmentalism. 2022 02.12.2022]; Available from: https://sfstandard.com/politics/purple-pipes-san-francisco-recycled-water-drought-environment/.

11. NBRC, A Guidebook for Developing and Implementing Regulations for Onsite Non-potable Water Systems. 2017, National Blue Ribbon Commission (NBRC).

12. Pakizer, K., et al., Policy Sequencing from the Bottom-Up–Transitions Toward Sustainable Urban Water Systems. Available at SSRN 4109954.

13. Rupiper, A.M. and F.J. Loge, Identifying and overcoming barriers to onsite non-potable water reuse in California from local stakeholder perspectives. Resources, Conservation & Recycling: X, 2019. 4: p. 100018.

14. SF, Onsite Non-potable Water Use: Guide for the collection, treatment, and reuse of alternate water supplies in San Francisco. 2012, City and County of San Francisco (SF): San Francisco, California, USA.

15. SFPUC, Final Urban Water Management Plan for the City and County of San Francisco. 2001, San Francisco Public Utilities Commission (SFPUC): San Francisco, California, USA.

16. SFPUC, WATER RESOURCES DIVISION ANNUAL REPORT: Fiscal Year 2021-2022. 2022, San Francisco Public Utilities Commission (SFPUC): San Francisco, California, USA.

17. SFPUC, Validated UV Systems. 2020, San Francisco Public Utilities Commission (SFPUC): San Francisco, California, USA.

18. SFPUC, San Francisco's Onsite Water Reuse System Projects. 2021, San Francisco Public Utilities Commission (SFPUC): San Francisco, California, USA.

19. SFPUC, Onsite Water Recycling: An Innovative Approach to Solving an Old Problem. 2022, San Francisco Water Power Sewer (SFPUC): San Francisco, California, USA.

20. SFPUC, Guidebook for Commissioning an Onsite Water Treatment System in San Francisco. n.d., San Francisco Public Utilities Commission (SFPUC): San Francisco, California, USA.

21. SFPUC, Onsite Water Reuse System Vendors. n.d., San Francisco Public Utilities Commission (SFPUC): San Francisco, California, USA.

22. SFPUC, et al., Non-Potable Water Program Guidebook: A Guide for Implementing Onsite Non-Potale Water Systems in San Francisco. 2018, San Francisco Public Utilities Commission (SFPUC), San Francisco Department of Public Health-Environmental Health (SFDPH-EH), San Francisco Department of Building Inspection-Plumbing Inspection Division (SFDBI-PID), San Francisco Public Works (SFPW),: San Francisco, California, USA.

23. SFPUC, et al., Onsite Water Reuse Program Guidebook. 2022, San Francisco Public Utilities Commission (SFPUC), San Francisco Department of Public Health-Environmental Health (SFDPH-EH), San Francisco Department of Building Inspection-Plumbing Inspection Division (SFDBI-PID), San Francisco Public Works (SFPW), : San Francisco, California, USA.

24. Sharvelle, S., et al. Risk-based framework for the development of public health guidance for decentralized non-potable water systems. in WEFTEC 2017. 2017. Water Environment Federation.

25. SWRCB, Title 22 Code of Regulations. n.d., State Water Recources Control Board (SWRCB): California, USA.

26. Wagner, T. R., Nelson, K. L., Binz, C., & Hacker, M. E. (2023). Actor Roles and Networks in Implementing Urban Water Innovation: A Study of Onsite Water Reuse in the San Francisco Bay Area. Environmental Science & Technology.

27. WJW, Onsite Non-Potable Water Reuse Public Guide. 2018, WJW Foundation.