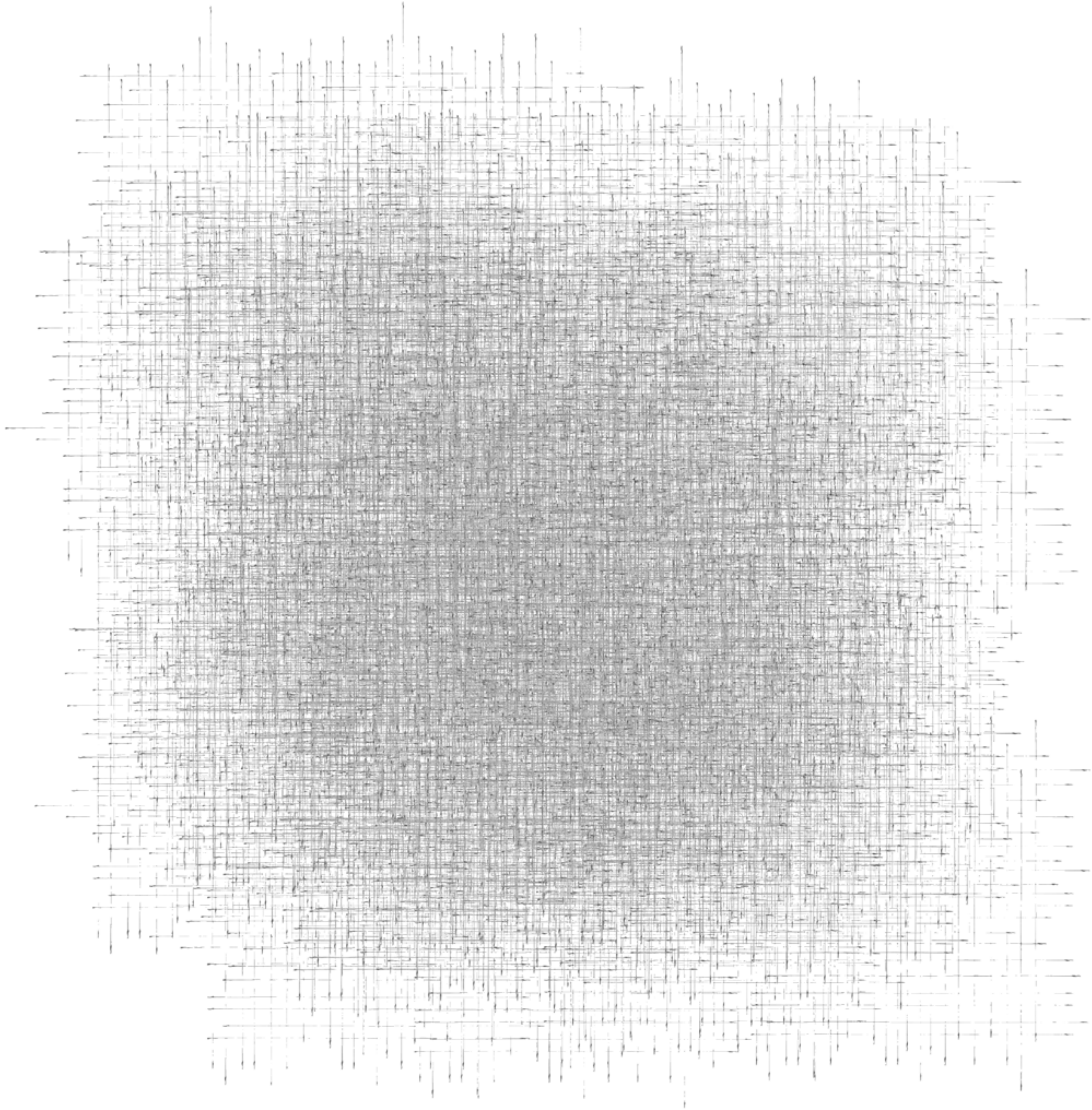
WATER HOSPITALS



Water Hospitals

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Statement

Combined sewer overflows often occur in older urban neighborhoods of Canadian cities and municipalities. Many of these areas are unable to accommodate infrastructure upgrades needed to mitigate this problem. To alleviate combined sewer capacity issues, wastewater treatment is required at the source of the overflow. The objective of *Water Hospitals* is to identify and develop the architectural characteristics needed to successfully facilitate the urban integration of wastewater treatment.

Methodology

Canadian wastewater statistics, facts and history will be researched and presented to better understand Canada's current position on wastewater treatment, as well as the potential problems inherent in our existing wastewater systems and infrastructure.

Public aversion and opposition to wastewater treatment processes will be explored to better understand the perceived risks ingrained in wastewater treatment. Strategies that positively influence risk perception, and therefore public aversion, will be synthesized from existing sociological and psychological research. An architectural analysis will be applied to demonstrate how these strategies can translate to architectural elements and characteristics. Precedent research will show how these characteristics have positively influenced public perception of wastewater treatment in conventional facilities.

Functional requirements will be selected from components provided by manufacturers of Canadian wastewater treatment systems. Programmatic requirements will be derived from system needs as well as from research synthesized from risk perception mitigation strategies.

A list of the requirements for the successful urban integration of wastewater treatment will be established. A prototype 'Water Hospital' will be developed from these requirements to demonstrate proof of concept for the project.

The focus of D9B will be to design a Water Hospital through the architectural application of the research presented in D9A.

Figure 1: Wastewater Treatment Facility. Image courtesy of Accessfayetteville.org.

Wastewater Treatment

Overview

To the left is a wastewater treatment facility. There are over 3,500 of these in Canada.[1] In most cases, storm and sanitary sewage is brought to the treatment facility through a sewer, where it is treated and discharged into a reservoir, river, lake or ocean.

Wastewater effluents are the largest source of pollution by volume to surface water in Canada, with over 150 billion litres of untreated and undertreated wastewater discharged into our waterways every year.[2] Municipal wastewater effluents represent one of the largest threats to the quality of Canadian waters.[3]

Sewage is often discharged directly into surface water if a treatment facility does not exist. Many Canadian coastal communities discharge untreated waste in this manner.[4] Other communities, including the majority of coastal communities and 15% of inland communities, are only able to achieve basic treatment of their wastewater before discharge.[5]

Sewer overflows are another major contributor to surface water pollution. Wet weather events can cause a sewer system to overflow, forcing raw sewage to bypass treatment altogether and spill directly into waterways.[6] Sewer overflows are common in combined sewer systems underneath Canadian cities,[7] and the architectural address of this issue is the focus of *Water*

Figure 2: Combined sewer overflow. Image courtesy of Lineal.co.uk.

Combined Sewer Overflows (CSOs)

There are two types of wastewater collection systems: combined and separated.[8] Combined sewer systems are designed to collect rainwater runoff, domestic sewage, and industrial wastewater in the same pipe.[9] Separated sewer systems collect sanitary and storm water separately.

Combined sewers were typically installed in North America from 1880 to 1960, and are still in operation in older areas of most Canadian cities.[10] The overflows caused by this type of sewer system were recognized as leading to pollution problems in the 1950s, influencing the design and implementation of separate sewers.[11] Since 1985, no Canadian jurisdiction allows for the construction of new combined sewers, although existing ones may be replaced or rehabilitated.[12]

Combined sewer systems overflow during wet weather events. During dry weather, sanitary sewage and any storm water are carried from the combined sewer to the wastewater treatment facility. During heavy rains or snow melts, the combined sewer cannot handle the volume of storm water entering the system. To prevent flooding and sewer backups, the excess wastewater and storm water is directly discharged into the nearest source of surface water.[13] These combined sewer overflows (known as CSOs) contain untreated human and industrial waste, toxic materials, and debris. They are a major water pollution concern.[14]

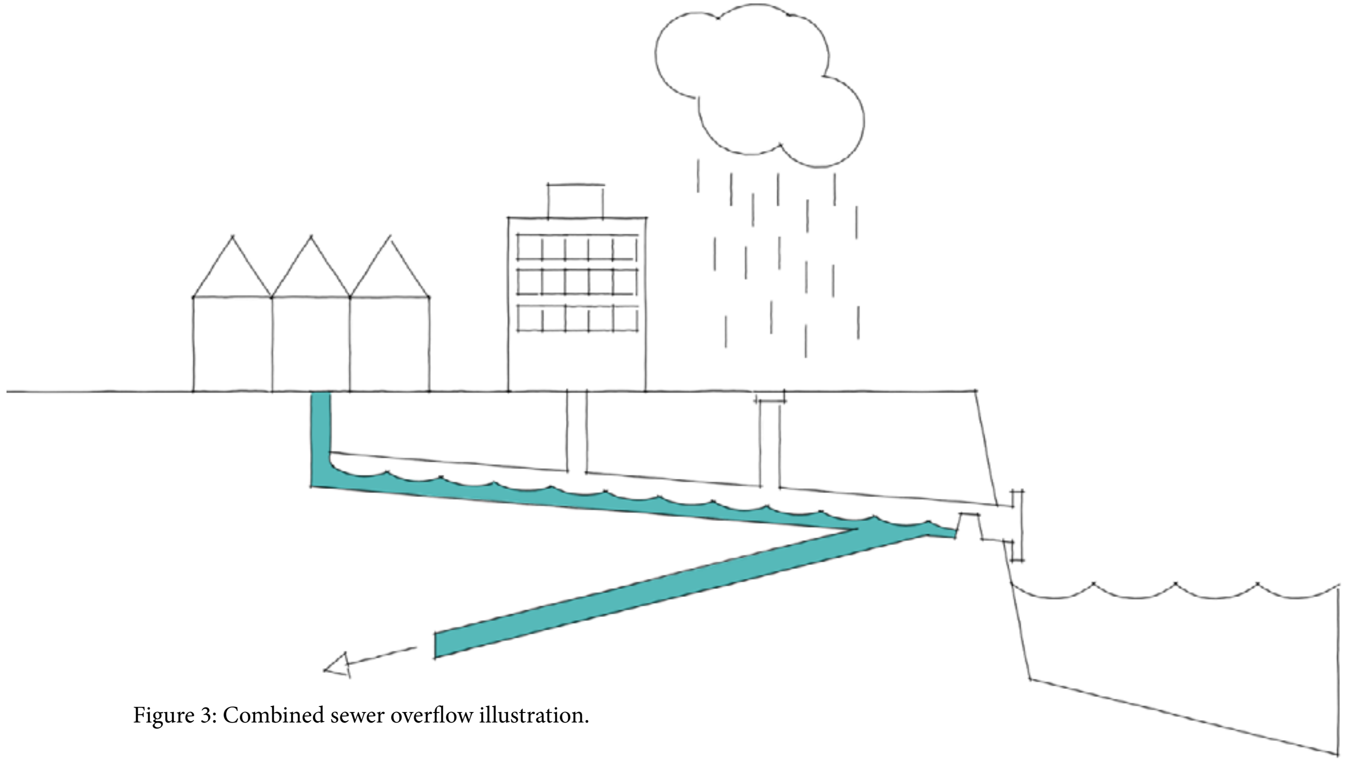


Figure 3: Combined sewer overflow illustration.

As population density increases in urban neighbourhoods with combined sewers, the frequency and severity of CSOs will worsen.[15] Climate change has increased the frequency of wet weather events, posing serious risks for environmental and human health.[16]

The practice of discharging overflows during the normal operation of combined sewer systems is accepted by the Ministry of the Environment.[17]

Government Response and Regulation

At time of writing, all Federal and Municipal regulations regarding wastewater treatment make concessions for CSOs to prevent sewage from backing up into streets and buildings.

The *Canada-wide Strategy for the Management of Municipal Wastewater Effluent* (2009) allows for CSOs during spring thaws, during emergencies, or when part of an approved combined sewer overflow management plan.[18]

The Ministry of the Environment and Climate Change's provincial *Procedure F-5-5* (2014) aims to eliminate CSOs during dry-weather periods (April 15 to November 15), except under emergency conditions.[19] It is not enforceable.[20]

The Ministry of the Environment, under the *Ontario Water Resources Act* (2011), justifies CSOs when there is a significant increase in wastewater due to a storm or spring thaw, when there are equipment or other operational problems in the treatment facility, and when population or industrial growth exceed the design capacity of the treatment facility.[21]

The federal *Wastewater Systems Effluent Regulations* (2012) is the first national sewage treatment standard that sets National Performance Standards for effluent quality from all municipal, community and government wastewater facilities that discharge municipal wastewater effluent to surface water. The National Performance Standards do not apply to combined sewer overflows.[22]

Mitigation Efforts: Sewer Separation

There are a number of ways of mitigating CSOs. One method is sewer separation. This involves disconnecting all storm or sanitary connections to the existing combined sewer, and re-connecting them to a new secondary sewer. Sanitary sewage is brought to the treatment facility while storm sewage (often containing contaminants from roads, roofs and other surfaces) is discharged directly into surface water.

Installing a second sewer can be a difficult undertaking. Most urban neighbourhoods with combined sewer systems are often considered the 'old' part of the city, and have intensified over time. As a result, complete separation of sanitary and storm water flows can include extensive construction and construction-related impacts.[23] The Environmental Commissioner of Ontario states that "in older built neighbourhoods, the extent of destruction (for sewer separation) may simply be beyond all reasonable limits with respect to the functioning of the city."[24] In many cases, cities have only been able to separate a portion of their combined sewers, due to high costs and/or physical limitations inherent in a separate system.[25]

Another potential issue with sewer separation is that storm water effluent is no longer treated before being discharged. In cases where surface runoff is of a poor quality (highly urban areas, for example), storm water discharges can lessen or offset any positive impacts from sewer separation.[26] In Atlanta, GA, sewer separation was estimated to increase pollution to local creeks.[27] In other instances, such as North Dorchester, MA, separation of sewer infrastructure was not estimated to significantly decrease pollutants.[28]

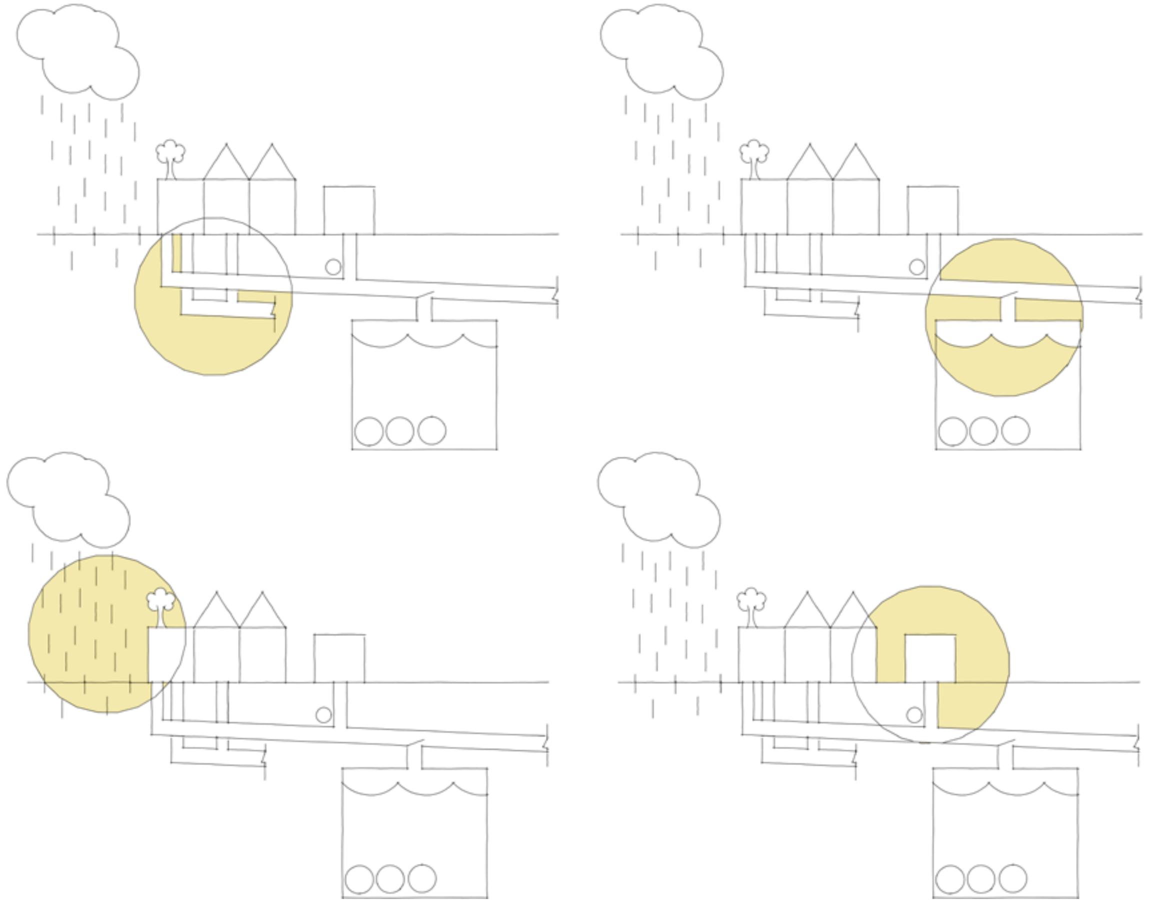


Figure 4: Mitigation methods for combined sewer overflows. From top left to bottom right: 1. Sewer separation. 2. Deep storage tunnels. 3. Green infrastructure. 4. Decentralize strategies.

Sewer separation can be cost-prohibitive, if not entirely unaffordable.[29] It is estimated that 105.9 billion dollars will be needed to control CSOs and manage storm water systems in the US.[30] Costs increase with site building density, as separation of a combined sewer system involves disconnection of all storm water draining structures, sump pumps and roof and footer drains".[31]

The City of Ottawa is in the process of separating most of its combined sewers. The cost of the work is estimated at $750,000,000.00, and will require another 25 years to complete at the time of writing.[32] Approximately one third of these sewers will remain combined due to the poor quality of storm water.

Mitigation Efforts: Deep Storage Tunnels

The most common approach to CSO mitigation involves the construction of 'deep storage tunnels'.[33] These are large tunnels; 15-80 feet in diameter and often miles long. They can take years or even decades to build. During a period of wet weather, excess effluent is stored within the tunnels until the wet weather event is finished and the system can resume normal operations. Stored effluent is then pumped back into the sewer system at a manageable rate.

For the best part of two decades, deep storage tunnels and CSO interceptor systems have formed the central spine of projects that many of the largest cities in North America have been obliged to adopt to reduce overflows of foul and polluted water into surface water.[34]

Deep storage tunnels are considered "end-of-pipe" solutions, offering the quickest fixes.[35] They are referred to as 'gray infrastructure', and are some of the largest engineering projects in North America.[36] Deep storage tunnels are expensive, with construction costs ranging from hundreds of millions to billions of dollars. There were over 17 billion dollars of CSO-related works agreed to in 2010 and 2011 in the US alone.[37] Deep storage tunels often require enormous pumps, pumping infrastructure, motors and test rigs.[38] The 5 mile Lee Storage Tunnel in London requires several 54-ton 'Super Pumps', and will be the most expensive water project ever undertaken in the U.K.[39]

Large projects often come with large problems. Geo-technical challenges can make deep storage tunnels economically unfeasible.[40] Resolving issues with tunnel construction and maintenance can be very time-consuming, which is inherently dangerous when working with septic gasses without proper monitoring and ventilation.

The scale associated with deep storage tunnels can lead to usage issues. In order to mitigate severe wet weather events, a properly sized tunnel or tank will only operate at a fraction of its full capacity during dry weather. This can translate to hundreds of millions of gallons of empty storage space throughout the year, which can be perceived as a low return for value.

Like most CSO mitigation efforts, deep storage tunnels are in reality only a temporary solution. An increase in urban density and wet weather events as a result of climate change will mean that even the biggest infrastructure projects will eventually be unable to cope with the additional volume. The city of Ottawa's *Environmental Study Report* for the Ottawa deep storage tunnel notes that a 15% increase in rainfall results in a 72% increase in storage requirements.[41]

Mitigation Efforts: Green Infrastructure

Green infrastructure refers to "a range of storm water control measures that use plant/soil systems, permeable pavement, or storm water harvest and re-use, to store, infiltrate, or evapotranspirate storm water."[42] Projects include green roofs, alleys and streets, bioretention swales, permeable paving, greywater re-use, tree-planting, re-creation of previously existing waterways and other projects.[43] Hierarchically, green infrastructure is the most effective solution in mitigating discharge, as it deals with storm water at the source.[44] Green infrastructure has been shown to reduce storm water discharges by retaining rainfall from small wet weather events,[45] reducing the volume of CSOs within combined sewer systems.

The success of green infrastructure relies on a significant amount of smaller projects, the scale of which can be expensive and difficult to manage operationally when pitted against immense issues such as storm water retention and CSOs. As green infrastructure projects slowly and naturally treat storm water, they are often ineffective at controlling sudden peak loads. Washington, D.C. has estimated that green-roof installation on most eligible buildings will yield a 6-10% reduction in CSOs. The City of Portland has estimated that full downspout disconnection (as a result of city-wide successful green infrastructure projects) will only lead to a 20% reduction in peak CSO volumes.[46]

Decentralized Strategies

One potential method of mitigating CSOs is through the incorporation of mid-scale, decentralized strategies into an otherwise centralized system. Locally-scaled treatment facilities are connected to main intercepts and sewer branches, where they can treat and discharge a relatively small amount of effluent (anywhere from 1,000 to 1,000,000 gallons per day). Decentralized systems are flexible solutions due to their small size. They are appropriately scaled for small or sudden volumes of effluent at local levels, with greater sensitivity to local contexts.[47]

Decentralized strategies have been proven effective in rural areas,[48] in smaller municipalities with limited sewer infrastructure,[49] and in a number of third-world applications.[50] They allow for effluent to be treated close to the source, requiring minimal sewer infrastructure upgrades. They tend to be more manageable in terms of scale than grey and green wastewater treatment projects, and can be up to hundreds of times less expensive than large-scale infrastructure upgrades. Through partnership with architectural intervention, decentralized systems can mitigate many of the inherent constraints within conventional treatment facilities.

Public Aversion: The "Yuck Factor"

In addition to requiring a great of deal of space, conventional wastewater treatment facilities need to be sited by a river, lake, reservoir or ocean for discharge purposes. They typically only employ primary and secondary treatment, which necessitates large, open tanks of effluent that produce unwanted noises and odours. Conventional treatment facilities are generally sited away from communities, having adopted an industrial typology as a result of a development pattern that limits public awareness and interaction. Their design does not in any way facilitate a meaningful public experience, and, for this reason, conventional wastewater treatment is generally kept away from the public.[51]

Many of these limitations can be overcome through engineering and technology. Smaller treatment facilities coupled with atypical discharge methods (sub-surface drip irrigation, industrial cooling, greywater re-use, groundwater recharge, or even potable direct and indirect use) can surmount site and scale constraints common in conventional wastewater treatment facilities. Issues of noise and odour can likewise be mitigated through technology, with several noise and odour-free treatment facilities existing across North America.

Despite these technological achievements, wastewater treatment plants are generally regarded with distaste and disapproval from the public. Fear of airborne hazards, respiratory infections and gastrointestinal issues, and pests are all perceived risks undeterred by the technological advances that ensure public health and safety in modern treatment facilities. Public opposition and aversion, currently considered the greatest obstacle to many new and socially controversial wastewater treatment projects,[52] goes beyond engineering solutions. In order to achieve successful urban integration of wastewater treatment, public perception of the risks associated with the treatment process must change.

Public opposition to wastewater treatment programs, projects, and re-use exist because of perceived risks to our health, safety, and environment that we associate with wastewater and sewage.[53] Leading psychological and social theories maintain that this risk is borne of a biological aversion to anything that might make us sick.[54] The feeling of dread and disgust associated with wastewater is often referred to as the "yuck factor" (a term initially coined by Leon Kass in *The New Republic*) and often defines public resistance to wastewater treatment and re-use projects.[55]

There are a number of sociological studies (predominantly funded by governments that contend with limited drinking water supply) that have examined these risks and have developed strategies that can influence how people perceive them. Social theories posit that risk perception is a culturally standardized response, where risks are often shared by similar groups of people.[56] Risks identified as "acceptable" by scientists (who generally agree wastewater treatment and reclamation is a technically safe and feasible process[57]) are different from those identified as "acceptable" by the general public because each group employs different rationalities, norms, and beliefs when evaluating risk.[58] It is therefore imperative that we raise the general public's standards in terms of risk evaluation.

Figure 5: Image courtesy of Overstock.com

To do this, psychological and sociological research has been synthesized into four major strategies that can positively impact risk perception, thus alleviating public aversion. These strategies, when examined within the architectural paradigm, can translate to tangible design elements and characteristics through an understanding of the human response to space.

Trust

Research shows that trust has been identified as a central factor in determining public acceptance of perceived risks.[59] Social-cultural approaches stress that trust in experts, authorities, setting, and scientific knowledge is paramount to public acceptance of technological risks.[60] Synchronously, the level of public acceptance can be considered a function of the degree to which the institutions responsible for the management of risks are trusted.[61] This suggests that if one is able to change a person's risk and trust perceptions, one might also promote change in variables otherwise less receptive to change.[62] Conclusively, greater levels of trust can lead directly to lower perceived health risks,[63] as well as temper emotional responses and build public acceptance.[64]

The relationship between architecture and public trust is subjective at best, but may be explored through the architectural language of historically trusted buildings, including banks, churches, prisons and courts. As design is capable of creating environments that forge and strengthen networks of social connections, (thus facilitating confidence and reciprocity,[65]) an analysis of these trusted environments can identify internal commonalities and design practices that can foster trust.

American and Canadian commercial architecture in the late 19th and early 20th century applied common architectural conventions to a number of buildings whose success depended on the trust of the people. The National Banking Acts of the 1860s put an end to the 'free banking' era of America, and created a need for a nationalized system. A 'stabilized' architecture that would help quell the public's hesitancy in depositing and lending wealth resulted in a very centralized, recognizable, and durable form that could easily be tied to the function of the building. The temple front, derived from Greek and Roman antiquity and treated as a single compositional unit, became the distinguishing feature of many banks,[66] as well as many other public, institutional and religious buildings. While the use of Neo-classical elements was a stylistic response, what is important to note is that the consistency in treatment and strong visual presence helped banks exude much-needed norms and standards to promote the durability and predictability required by financial institutions.[67] The enframed block, another standard denoted by a two-to-three storey facade punctuated with columns, pilasters, an arcade, or similar treatment of suggestive classical elements, is another example by which banks and public buildings were able to enforce consistency through prescriptive commonalities.[68]

Figure 6: Buildings in which we trust our money, our freedom and our safety. From left: Girard Trust Company, Philadelphia. Supreme Court of Canada, Ottawa. Kingston Penitentiary, Kingston. Images courtesy of Huffingtonpost.ca, Theglobeandmail.com.
Figure 7: Savings Bank of Utica (1899), Bank of Edenton (1911), Bank of America (1923).

The commonalities between banks and other trusted public institutions reflect balanced, classical central models that influence the spatial organization of trusted buildings.[69] Without a recognizable, centralized pattern, a building's identity and address can lose definition. The original design for the Bank of Canada in 1936 was rejected specifically due to the lack of unity and regularity in the composition.[70] It was important that banks were rigid, predictable and 'heavy with norms' to regularize perception and become trusted over time.[71] Durable materials and strong, larger-than-life scales were employed to create buildings that could be both repetitive and distinct in future iterations, without becoming muddied within the urban fabric.

Transparency and Legibility

It has been argued that the invisibility and separation of wastewater removal and treatment systems can exaggerate and reinforce the public's concept of contamination.[72] By diminishing invisibility through transparent and legible design, public experience and interaction with water is increased, subverting the expectation that treatment facilities present risks to process, community, and quality of effluent.

The aesthetic ideal of transparency is to allow communication between disciplines,[73] through the promotion of continuity between spaces within the built form. Transparent facades, a common architectural element in buildings, blur the limits between interior and exterior, thus encouraging the public to participate and contribute to activities within.[74] In this way transparency supports the building's communication with the city.[75] The Centre Georges Pompidou (*Paris; Piano, Rogers and Franchini*), relies heavily on transparent architecture to bring exterior public spaces and streets into the constructed area.[76] Despite being heavily panned by critics upon opening due to its 'insensitivity' to the city streets around it,[77] over time the building has become an accepted icon of Paris. Rogers, "looking for transparency [and] the idea of a cultural centre that was truly open to everyone with nothing to hide from the public", has compared transparency in architecture to the concept of transparency in the organisation of a society, and therefore to democracy and openness, whereby the public can appropriate a building and its function. By blending exterior and interior faces, invisible functions and features become revealed through the concept of public interface.

Figure 8: At time of writing, a transparent toilet installation from the Collective Water Coalition sits in front of the Pompidou Centre. Image courtesy of Demotix.com.
Figure 9: From left to right: 1. Roelan Otten's projects in Amsterdam disguise public washrooms and sub-stations using facades that mirror the surrounding urban fabric. These buildings attract people's curiosity and help put a positive face on an otherwise ugly function, but do not educate or promote awareness of the process within. 2: The Exhibition Trench, Topography of Terror, Berlin (*Ursala Wilms & Heinz W. Hallman*). Heavily regimented architecture is used to effectively disseminate printed information depicting the Third Reich's rise to supremacy. 3: Nationwide Insurance Advertisement. The building is frequently mistaken for the headquarters of 'Coop's Paint', a fictional company, despite its typology. Images Courtesy of Madeinslant.com, Andberlin.wordpress.com, Advertolog.com.

Legibility within architecture "renders visible and identifies the activities taking place inside, forcing the concrete interaction of a building's functions with its architecture. A 'legible' building is one which, far from being anonymous and opaque, allows itself to be apprehended and decoded by the public."[78] Architecture emphasizes a building's legibility through layering and hierarchy. The Centre Georges Pompidou uses color to decode the mechanical and system elements, and establishes a strong 'inside-out' structural hierarchy to make the building approachable. Navigable circulation can also help render a form legible by providing hierarchy to the building's spatial experience.

Certain architectural conventions make use of contextual and stylistic 'cues' that take advantage of collective associations that have developed over time. Massing can help the public quickly identify a residential building from a commercial one, much in the same way that a building's complexity can help the public discern an institutional form from a corporate structure. These characteristics lead to typologies that categorize building functions. It is possible for a particular building function to transform, develop, or change its typology over time to better address legibility and transparency concerns. Hospitals, for example, have "unbundled" themselves over the years from the typical tower/podium typology in order to better respond to the community.[79] To address this response, hospitals have adopted the complexity and scale of institutional architecture standards, slowly transitioning from religious healing centers into civic enterprises that serve an active and legible role within the community.[80] Hospitals have further decentralized, forming small, individual 'groupings' that are easy to comprehend, resulting in a new building type that are open to the city. Through increased openness, transparency and legibility, hospitals have gradually moved from the city's edge to the city's center, where they have become a successful part of the urban fabric.[81]

Transparent buildings encourage the public to engage with spaces that they might not otherwise approach, and legibility ensures that public is able to read and understand the function of the building. These two practices are paramount in creating buildings that the public is more likely to perceive in a positive manner.

Education, Awareness and Benefits

It is well documented that education is a major factor in public acceptance, with surveys consistently demonstrating that persons who display positive attitudes to wastewater treatment are generally better educated than those who perceive treatment to be risky.[82] This is because a person's level of understanding directly influences how one perceives risk. By augmenting a person's level of understanding towards that of an expert, the terms of risk change accordingly. For this reason, awareness and education are important factors in moving the public beyond their aversion to wastewater processes. Communities must understand why unconventional wastewater treatment strategies are necessary and beneficial in order to support them.[83]

There are many ways of improving the public's educational stance on wastewater treatment. Water recycling programs often recommend the distribution of educational materials to residents and businesses in order to mitigate the 'toilet-to-tap' mentality.[84] Such programs can manifest themselves architecturally through creation of spaces or expanses for the solicitation or advertisement of educational material. Most state-of-the-art wastewater treatment plants now include educational facilities, learning centers, or open laboratories, and many engage with the public through educational campaigns, scholarships, or partnerships with environmental and scientific organizations.

Within the parameters of architecture, educational spaces are largely programmatic in nature. Physical spaces for learning, whether direct or indirect, often hinge on a need for social infrastructure that permits formal or informal social interaction.[85] Informal social interaction refers to indirect learning, and has precedent in art galleries, urban installations, tours, and museum exhibits. These indirect learning spaces promote collaborative inquiry by providing an opportunity to engage in and present work publicly.[86] The success of these spaces and their exhibits depend on the space's ability to attract visitors, capture their curiosity, and engage them with a narrative. Additional factors include the space's ability to filter content into easily absorbed themes, and to present information in a linear format.[87]

Figure 10. The Phoenix Financial Center employs a punch card façade to let people know what goes on within. 5: Longaberger Baskets Headquarters, Ohio. 6: House of Free Creativity, Turkmenistan. Images courtesy of Bridgeandtunnelclub.com, Wikipedia.com, Uiowa.edu.

Architecture can thus engage the public by providing circulation patterns that allow the user to receive information in a chronological or hierarchical manner. By filtering visible content and ensuring that spatial relationships continue an easily digested narrative, the public is indirectly informed of a history or process. Museums and monuments often take advantage of these architectural strategies. Framed views, light and shadow, and positive and negative spaces can direct a user's curiosity to specific areas of a building, while cultivated circulation routes can ensure that a person reaches their destination in a controlled manner.

CSO awareness can be generated by emphasizing the benefits of wastewater treatment. Sociological and psychological research shows that positive, euphemistic language can help selectively identify and frame a situation in a way that allows the public to alleviate a perceived risk. The delineation of the benefits of the building's function can influence risk perception,[88] as it is a human tendency to minimize risk when dealing with something considered to be positive.[89] Buildings can take advantage of this tendency through self-promotion of their architecture and processes, mitigating public aversion.[90]

The benefits of wastewater treatment facilities heavily outweigh the risks. The processes used are safe and effective. Reductions in sewer overflows lead to less surface water pollution, which can be demonstrated through local lenses in the form of fewer beach closures and less water contamination. Implying that the establishment of safe, urban, locally-sourced treatment will allow children to swim without being exposed to a multitude of diseases is a persuasive way to frame an argument. Discharge methods can also be spun in a positive manner.
Most North American cities use approximately 10% of their drinking supply for irrigation purposes – knowing that an urban treatment centre may allow residents to water their lawns to their hearts' content, or provide greywater without affecting the city's drinking supply can augment a building's positive status. Educational spaces that directly and indirectly advertise these messages is extremely important. Designing positive or symbolic architecture that demonstrates the quality of treated effluent can further overcome negative emotional responses to wastewater treatment.[91]

Figure 11. 58 Joralemon, Brooklyn, aka NYC Transit Authority Subway Ventilator (left). 640 Millwood Road, Toronto, aka Hydro-Electric Sub-Station 'D' (right). Images courtesy of Brownstoner.com and Blogto.com.

Positive Form

Form itself is an effective tool in determining whether or not a person will be adverse to a process. It has been noted in numerous psychological research articles that people will avoid interaction with forms associated with undesirable, adverse or risky behaviour. Experiments have demonstrated that people are unwilling to drink out of sterilized bedpans, wash themselves with clean toilet brushes, or eat food out of sanitized trash cans, despite being made to understand that there is no actual risk to any of these activities.[92]

Conversely, humans can create mental barriers to an object's history that allows them to ignore potential contamination.[93] These mental barriers allow people put aside adverse thoughts when handling 'positive' objects that may have been exposed to any number of contaminants, such as money or restaurant utensils.[94]

In architecture, positive form association is most prominently seen in the form of 'fake buildings' and faux facades. Urban infrastructure with perceived risks, (subway ventilators, energy conversion stations, public restrooms and cell phone towers to name a few), are often draped in 'friendly' facades that resonate positively with the public. By transforming the exterior form of the building, certain perceived risks can be successfully mitigated.

If the risk associated with a specific function is primarily aesthetic due to negative form, these measures may be quite successful. If the perceived risk relates to health or environmental factors, additional mitigation strategies are often required in conjunction with positive form. Electrical sub-stations disguised as houses may negotiate a community's apprehension with its original form, but will likely not mitigate an immediate neighbor's perceived health risk. The architecture of faux facades is successful enough to warrant repetition throughout other communities and cities, but it may not be the 'right' architecture required to solve the entire problem.

As an example, cell phone towers are often considered 'risky' due to perceived safety issues with radio frequencies, despite studies showing that cell phone tower frequencies are safe and non-ionizing.[95] As a result, cell phone providers often disguise their towers in an attempt to appease the public. However, despite the friendlier form, it is not unusual for public opposition to exist.[96]

Positive forms do not have to contradict the idea of transparency and awareness: it is possible to maintain and enhance forms that render the conventional treatment facility legible (circular and elliptical tanks, rotating mechanisms, secondary hatching, etc. . .[1]) while curating its architectural characteristics in a way that promotes positive form association. Developing and understanding a positive, yet legible, architecture is essential to the success of a distrusted function within an urbanized environment.

[1] See Appendix A

Figure 12. Cell phone towers concealed as trees, water towers, and church steeples. Images courtesy of Wikimedia.com, Weburbanist.com, Nationalgeographic.com, Paloaltofreepress.com.

Understanding how these strategies are employed within an architectural context is an important step in developing the elements and characteristics needed for the urban integration of wastewater treatment. To be successful, an urban treatment facility must be trusted, understood, and also educate the public. By examining a number of successful, centralized treatment facilities, we can better understand how architecture can adopt and promote strategies that change how the public perceives risk. Without architecture, many of these facilities would remain undesirable, despite being fully functional and technically risk-free. Through the architectural translation of public awareness, education, trust, transparency, legibility, form, and delineation of the benefits of treatment, the following precedents have become publicly-accepted examples of centralized treatment.

Figure 13. The evolution of the electrical sub-station. (From top left to bottom right): 1. Exposed sub-stations, while technically safe when designed in accordance with engineering standards, are perceived as a risk by the public. 2. Sub-stations housed in simple shelters are often insufficient to alleviate the concerns of the public and are undesirable in public spaces. 3. The 'box' begins to mimic recognizable, 'friendly' forms. 4. Sub-stations are fully disguised as residential buildings. This mitigates concerns from external sources, but does little to augment the trust, legibility, education or awareness of the community. 5. Sub-stations begin to take on their own design in an attempt to become 'domesticated' and to intelligently integrate into the urban fabric.[97] Images courtesy of Shutterstock.com, Google Maps Ottawa, Google Maps Victoria, Wikipedia.com, Unstudio.com.

Precedents

Overview

The following six precedents have been selected for their success and innovation in waste treatment. These treatment facilities are industrial in scale and service population equivalents ranging from mid-sized municipalities to large cities. They are sited in rural, industrial, or ex-urban areas. These precedents successfully overcome public aversion, and in many cases have received a great deal of public acclaim, leading to additional funding to increase their scale of operation.

Brightwater Treatment System, Washington

Brightwater Treatment facility (Mithun Architects) is a large wastewater treatment plant in Snohomish County, Washington, completed in 2011. The treatment facility occupies 114 acres and includes storm water treatment and retention, as well as constructed wetlands.[98] The plant treats an average of 36 million gallons of wastewater per day,[99] and services approximately 1.4 million people in the Seattle area.[100] It uses advanced treatment systems (suitable for all non-potable uses according to Washington State laws[101]), is a 'zero odour' facility, boasts an educational center, and employs a number of architectural design considerations.

The treatment facility is rurally located due to the 'simple truth' that nobody wanted a sewer plant near their home, business, or beach.[102] This 'truth' cost Brightwater considerably, requiring substantial infrastructure upgrades that significantly increased the project's final budget to 1.86 billion dollars. 13 miles of pipeline required construction using tunnel boring machines that cost the state a significant portion of its budget [103]. One boring machine became stuck 300 feet underground in 2009, while the other became stuck later that same year, substantially delaying the project.[104]

To help Snohomish County accept and adopt such a large facility, the Brightwater Educational Center acts as the public interface of the treatment facility, promoting awareness and providing education on wastewater treatment in a space conducive to beneficial programs and campaigns. It has been an extremely successful endeavour. Snohomish residents frequently book events at the treatment center, and even wedding receptions now take place steps away from where raw sewage is processed.[105]

To illustrate the benefits of Brightwater, the facility is heated using methane generated from secondary treatment in a transparent setting that allows visitors to understand the process. Reclaimed water from the treatment facility is used for greywater purposes, including all landscaping irrigation and toilet flushing.[106] To increase awareness, the design team worked with teachers early in the process to help plan out nearly 140 million dollars' worth of educational campaigns and community projects.

The architecture of Brightwater pulls away from the conventional industrial typology. The roofline and framed balcony express the idea of a return to water. Materiality remains somewhat industrial in nature, but is broken up into a more palatable scale through dissimilar perforation and openings that suggest aesthetic placement rather than functional necessity. This break in style and scale makes the treatment center more approachable to the general public.

Groundwater Replenishment System (GWRS), Orange County

The Groundwater Replenishment System (HOK Architects) in Orange County is a 'second phase' wastewater treatment facility that has been operating since 2008 and is the largest water purification project of its kind in the world.[107] Wastewater is first treated at the Orange County Sanitation District and is then pumped to the GWRS where it is micro-filtrated, undergoes reverse osmosis, and is exposed to UV light and hydrogen peroxide to remove trace organic compounds at a parts-per-trillion level.[108] Effluent is then returned to the groundwater basin and mixed with the county's drinking water supply.

The GWRS overcame the 'toilet-to-tap' misperception through trust, transparency and awareness. A large part of the GWRS' success is due to the architectural "publication" of the building's benefits to the community. The GWRS offers open tours of their system, employing large glass expanses to showcase the treatment process. Instead of hiding or "dressing up" utilitarian industrial systems, the architecture helps tell the story of the entire process to the local community.[109] A linear spine that follows the treatment process gives organisational clarity and character to the narrative, which concludes in the user being offered a glass of water from an expert.[110] As with Brightwater, pro-active public outreach and education regarding advance wastewater purification is important to garner support for future GWRS-like projects that are being planned around the world.[111]

The GWRS's 'Advanced Water Quality Assurance Laboratory', a static, institutional building with rigid geometry and prominent massing, is open to the public, allowing the community to place their trust in the science and research behind the system by providing a better understanding of it. In April 2010, the GWRS received Federal and State funding to increase expansion due to its success.[112]

Figure 14 (Overleaf): Brightwater Treatment Center. Image courtesy of Mithun.com.
Figure 15: GWRS. Image courtesy of HOK Architects.
Figure 16: Advanced Water Quality Assurance Laboratory. Image courtesy of Ocwd.com.

Sechelt Wastewater Facility, BC (In Construction)

The Sechelt Reclaimed Water Facility (SRWF) will replace the existing Ebbtide Wastewater Treatment center in sub-urban Sechelt, BC. The existing treatment center is sited near residential neighborhoods and subjects nearby residents to noise and odours.[113] The SRWF is designed to integrate seamlessly into the built environment and will be more akin to a park than a traditional wastewater treatment facility, promoting a much more positive form to the surrounding community.[114] To help bridge the gap between wastewater treatment and the public, the facility will center around a gathering place that provides educational and aesthetic value to the community. Approachable architectural forms, pleasing, non-industrial massing and smaller volumes help the building fit in with its surrounding context and environment.

The Sechelt Treatment Facility will metabolize organic compounds with a 'Fixed-Bed Activated Biofilm' housed in a transparent greenhouse setting. The process will be highlighted through advertisements within the space. The resulting effluent is suitable for indirect potable use and can be used to irrigate the park. According to Maple Reindeers Inc. , (the consortium engaged to construct the project), the goal is to transform the historical view of wastewater treatment from a place to be hidden to a place to be celebrated; where people can come and learn about natural treatment processes. Typical conventional forms and characteristics are hardly employed in the design, blurring the lines between industrial, library, and institutional typologies. The site is designed with a training and education focus and includes research scholarships for experts in the field.[115]

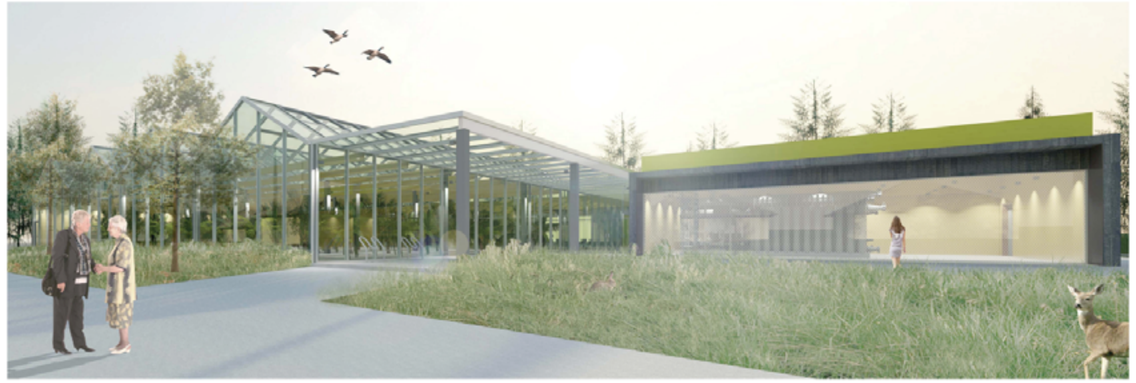


Figure 17: Sechelt Wastewater Treatment Facility. Image courtesy of Sechelt.ca.

BIG's Amagerforbraending Incinerator (In Construction)

The BIG Amagerforbraending Incinerator is a waste-to-energy plant that hopes to merge public interaction with conventional, 'functional boxes'.[116] The plant produces 200,000 tons of carbon dioxide each year, illustrated by a giant smoke ring released for each ton of CO_2 produced. The ski slope was added in hopes of bringing a social infrastructure component to the existing program, rather than simply creating a beautification project, creating a new typology.[117]

The building's exterior cladding is made up of a series of window boxes that perforate an opaque shell, opening up the building to nearby residents and encouraging them to appropriate and understand the systems within.

The ski slope combines the strategies of trust and transparency through direct public interaction made possible through a hybridization of program that allows positive connections to be made between waste treatment andthe country's national pastime. BIG refers to the concept as "hedonistic sustainability", or sustainability without sacrifice.[118] By highlighting the benefits of the new waste-to-energy plant, the perceived risk is lessened. One unique aspect of the ski slope incinerator is that it is relatively close to an urban center. This integration allows trucks to drive shorter distances to the plant, which creates a number of economic and environmental benefits. Because the incinerator is so close to residential communities, it's important that the architectural aesthetic blends the building in with its surroundings. The building needs to be pleasing to look at, while still maintaining the conventional cues of a power-generating station.[119] The incinerator will be functional in 2017 and has generated a great deal of positive publicity.

Figure 18: BIG Amagerforbraending Incinerator. Image courtesy of Inhabitat.com.

Johns Creek Environmental Campus, Fulton County, GA

The Johns Creek Environmental Campus (Fulton County, GA) is the second largest membrane bioreactor wastewater treatment facility in North America. It was designed in conjunction with community involvement to gain public acceptance in order to avoid the "not-in-my-backyard" mentality.[120]

The facility is adjacent to a community of upscale residences. The study notes that gaining the public's trust was an ongoing part of the initiatives undertaken by the design-build teams as well as Fulton County. The concerns levied by the community during public meetings were developed into a number of architectural responses that speak to a typology of familiarity and trust. These elements include adopting a non-industrial design (through the use of residential modules, scales, patterns and materials), employing vernacular architecture and using common materials local to the area. Queen-sized brick was used to suggest that the building was old, and the tinted mortar (to match the fired clay) helped cement this impression. A variety of façade treatments and openings gives suggests the building was constructed in phases over time. An education lecture hall and teaching labs were added to the program to facilitate public awareness.

The penultimate goal of the design was to establish an institution in which the community could place their trust. The laboratories and lecture halls were primarily constructed to educate school children about wastewater treatment, but also provide a place for on-site educators. A number of noise and odour abatement methods were included in the building design, water features and ground irrigation make use of treated water. The architectural considerations along with state-of-the-art technology help create a facility that provides a vital role for the community while being a 'good neighbor'.[121]

Figure 19: Johns Creek Environmental Campus. Image courtesy of Thembrsite.com.

Newtown Creek, Greenpoint, NYC

Newtown Creek wastewater treatment plant (Ennead Architects) is the culmination of a long-term upgrade project that began in 1998 and will be completed in 2015.[122] The plant's notable characteristics include eight metallic 'digester eggs', which are derived from some of the more conventional forms associated with industrial facilities, but have been treated architecturally to resemble the tops of water bottles. The treatment facility also includes a transparent visitor center that conducts tours through the galleys that connect the digesters, allowing patrons to chronologically observe the steps required for treatment.

The components, structures and systems used in Newtown Creek are colour coded and tied to specific materials and forms, which serves to organize the plant both visually and functionally.[123] The scale is broken down in a manner distinct from the industrial typology, with narrow rectilinear panels giving the facility an almost museum-like quality. The galleys on top take hierarchical precedent and draw the eye upwards and away from the massing of the digester eggs.

Bright white lights define the plants' various functions at night, while a blue light unifies the rest of the components and acts as a beacon to adjacent communities. The visitor center invites the public to engage with the rest of the building, which depicts its equipment in a visible and easily-decoded manner. By developing a complex instead of an industrial area, the resulting form breaks free from the traditional industrial typology and attempts to create a new typology for large-scale urban work.[124]

The Newtown Creek treatment recently center expanded its operations to include an experimental 'food waste-to-energy' program that produces natural gas from the food scraps of New York citizens. The carbon reduction benefits of this program were heavily publicized to neighbouring communities.[125] These benefits will eventually expand to provide heat for nearby residents, and have helped bring the community on board with the rest of the treatment facility's programs and processes through positive program association.

Figure 20: Newtown Creek Digesters. Image courtesy of Designboom.com.

Functional Elements and Equipment

Overview

Many different wastewater treatment systems and processes currently exist in North America. While it is not the intent of this thesis to speculate engineering solutions, a cursory understanding of common processes and facility types will provide a basic understanding of the functional elements and equipment required for urban-integrated wastewater treatment

Treatment Levels

Wastewater treatment is typically broken down into three levels:

Primary Treatment: Sewage is pushed through a screen to separate out large solids and debris (this is sometimes considered 'preliminary treatment'). The remaining effluent is pumped to a large tank where it is allowed to settle. Floating scum is skimmed off the top, and heavier sludge is scraped of the bottom of the settling tank using rotating paddles, mechanical rakes or weirs. The remaining effluent is discharged. Effluent at this stage is brown, opaque and has an unpleasant odour.

Secondary Treatment: Secondary treatment involves the breakdown of organic matter through bacterial processes. Effluent is pumped into a concrete or steel tank where it is mixed with oxygen and bacteria. The bacteria digest organic matter. Effluent is often pumped back and forth between settling tanks and aerobic/anaerobic chambers to facilitate digestion. Secondary-treated effluent is often light brown in color, somewhat translucent, and may or may not give off odours, depending on the thoroughness and efficiency of the process. Secondary treatment is the most common form of treatment in Canada.[126] It does not treat "emerging contaminants": a long list of personal care products, pharmaceuticals, endocrine disrupting compounds, brominated flame retardants, and other chemicals that have become more prominent in our sanitary sewage over the last few decades.[127] Emerging contaminants require specific tertiary or post-tertiary treatment.

Tertiary Treatment: Tertiary treatment typically involves subjecting effluent to UV light to kill remaining viruses, pathogens and bacteria. Tertiary treatments may also employ reverse osmosis, microfiltration, or chemical disinfection. Adsorption, nanofiltration and reverse osmosis membranes are options for the removal of emerging contaminants.[128] Tertiary treated effluent is translucent and odourless, and can be suitable for irrigation or even potable uses.

Facility Types

Primary, secondary and tertiary treatments are achieved through a variety of different engineering processes, which necessitate a variety of equipment, systems and buildings. Common elements in wastewater facilities include settling tanks, clarifiers, contactors, lagoons, filtration pits, media beds, and a number of smaller buildings that house and power the necessary mechanical and electrical equipment.[2]

Auxiliary buildings often house systems that remove and re-use solids and other by-products of the treatment process. These systems include sludge dewatering (a process that produces biosolids), and methane capture (used to power treatment facilities).

In order to find a treatment facility capable of integrating into an urban site at an appropriate scale, the following criteria was presented to a number of engineering companies who specialize in the design and construction of wastewater treatment systems[129]:

- Minimal footprint
- Fully enclosable
- Noise & odour-free
- Minimum secondary treatment with potential for tertiary treatment

In every case, a pre-engineered wastewater treatment facility known as a 'packaged plant' was suggested as the best solution to the problem.

[2] The architectural characteristics of these components are presented in Appendix A.

Figure 21: Packaged plant. Image courtesy of Ashbrookcorp.com.

Packaged Plants

Packaged plants are pre-manufactured treatment facilities, typically used to treat wastewater in small communities, ships, casinos, apartment complexes, or individual properties.[130] They can treat anywhere from 1,000 gallons of wastewater per day (GPD) to 1 million gallons of wastewater per day (MGD). Capacity can also be expressed in population equivalent (PE),[131] with some packaged plants capable of serving up to 10,000 PE.[132]

Packaged plants generally consist of a number of steel or concrete tanks that work together in a self-contained, pre-fabricated system that can be installed above or below grade (several packaged plants do not function below 5° Celsius and may require enclosure.[133]) Monitoring of system components is done through computer controls linked to sensors to achieve precise control of timing, mixing and aeration. Complex systems such as these are unsuitable in areas where controls may be unreliable, poorly maintained, or where power supply may be intermittent.[134]

There are several common treatment systems used within packaged plants, including extended aeration, contact stabilization and sequence batch reactors.[135] These treatment systems typically produce fewer odour emissions, have smaller footprints, and have greater installation flexibility than conventional processes. [136]

The treatment system recommended by manufacturers is a membrane bioreactor, or MBR, system. MBRs biologically degrade waste products with membrane filtration (a form of microfiltration), and are very effective in removing organic and inorganic contaminants, as well as biological entities from wastewater.[137] They have been successfully piloted in specific-site projects, including water recycling in buildings, industrial wastewater treatment and landfill leachate treatment. MBRs are also being investigated as potential solutions for agricultural waste treatment, food processing waste treatment, herbicide and pesticide treatment, and the treatment of endocrine disrupting substances.[138] MBR packaged plants produce an extremely clean effluent capable of meeting stringent discharge guidelines, and can be suitable for potable reuse.[139]

MBRs use a relatively small amount of energy to operate and occupy a minimal footprint. They can have optional tertiary treatment processes easily added to the supply chain. MBRs also produce 60-80% less sludge than conventional treatment systems.[140] Several companies design and sell MBR packaged plants, including Siemens, Koch, Dynatech, Neosep, General Electric, Martin, Titan, Parkson, Bi Pure and VisGreen.

MBR packaged plants typically range from 8' – 20' width, and 7' - 15' height. Length varies according to capacity. Packaged plants are flexible in that smaller packaged plants can be arranged in tandem to achieve wider (or narrower) footprints.[141] Modular plants can fit in a shipping container, be assembled in a day, and run at nearly full efficiency after 72 hours (the time it takes for the bacteria and protozoa to 'seed'). Packaged plants are moderately noisy due to their blowers, which pump oxygen into aerobic tanks. It is not, however, difficult to design blower systems that produce less than 70 dBA of noise.[142]

Odour Control

Figure 22: Purafil ESD drum scrubber. Image courtesy of Purafil.com.

Wastewater treatment processes produce a number of compounds that are offensive to the human sense of smell. These compounds include hydrogen sulfide, ammonia, methyl mercaptan, carbon disulfide, biphenyl sulfide and dimethyl sulfide, which are commonly associated with the smell of rotting eggs and burning garbage.[143]

Traditional treatment facilities partially mitigate odour issues by being sited in open areas, or by covering their tanks.[144] The most common methods for odour control in odour-free sewage facilities are thermal oxidation, biological treatment, and chemical oxidation. Thermal oxidation essentially burns off odour causing compounds. It has high installation and operating costs, and is only used for very high strength odours.[145] Biological treatment is a simple and effective system to use, but requires a very large footprint. Chemical oxidation (scrubbing) is the best solution for situations with limited space. Chemical drum scrubbers are frequently used in wastewater pump stations and treatment plants (often in residential communities) and can treat airflows up to 1,000 cubic feet per minute.[146] Drum scrubbers are designed to be quiet, weatherproof, and maintenance free.

Sludge Processing and Dewatering

As wastewater settles, a by-product of thick sludge remains in the hopper of the settling tank. This sludge is metabolized by bacteria, becoming rich in organic nutrients. It is not uncommon for treatment facilities to 'dewater' this sludge (through screw or centrifugal action, and with the addition of thickening polymers or agents) and then sell the remaining caked material to farms as fertilizer. Sludge processing differs according to facility – some treatment plants pump sludge into a large open 'bed' that dries during the winter months. Other processing plants direct sludge into large geo-textile bags (twenty-yard "dumpster bags" are common options for transportation[147]) or drums. Smaller plants often employ polymer 'dry bags' that hold approximately 10-20 gallons per bag and require 2-6 months of storage to fully dewater. Once sludge has dried to approximately 30%-90% solids (percentages vary by use and according to scale of economy; sludge with a higher solid content is lighter and costs less to transport), it can be sold to farms, used in greenhouse applications, or carted off to a landfill.[148] Small dewatering packaged plants can thicken and dewater up to 5,300 litres of sludge a day. These systems automatically fill 17-gallon dry bags and occupy a small footprint (approximately 7' long by 5' wide by 5' high).[149] On-site dewatering produces unpleasant odours and is designed in conjunction with odour control equipment.

Sludge processing and removal is a programmatic element that requires processing space, greenhouse space, shipping space, road access, or a combination of the above. A 100,000 gpd MBR packaged plant running at full capacity can expect to produce approximately 500 gallons each day,[150] but this number is expected to be far less for combined sewage with a high percentage of storm water.

Solids, Grit, Fat, Oil and Grease

Oversized materials are sometimes flushed or forced down toilets, or carried into a sewer by surface runoff. Examples include diapers, plastic bottles, or even 2x4s. In a conventional facility, large solids are removed by directing sewage through a bar screen. The solids are then either compacted and hauled to a landfill or recycling center,[151] or ground up and added back into the effluent stream to be treated along with the rest of the sewage.[152] Larger bar screens, known as 'trash racks', can be installed within a sewer system to divert large solids to a specific interceptor.

Once large solids have been screened out or shredded, it is important to remove any remaining grit from the effluent. Grit refers to smaller materials that do not easily break down biologically; this includes sand, cinders, egg shells, gravel and coffee grounds. Within an MBR system, grit is generally removed in two ways: either by forcing the effluent through a fine metal screen that filters out all particles larger than a few millimeters,[153] or by allowing the effluent to settle, causing heavier grit to fall into a hopper at the bottom of the settling tank. Grit is typically transported to a landfill. Grit removal significantly extends the life of the wastewater treatment equipment.[154]

Fat, oils and grease (FOG) will coagulate around particles within the effluent and form marble-sized grease balls. These can be skimmed from the top of settled effluent with mechanical rakes or paddles and removed, often during the same stage as grit removal. FOG collected from packaged plants is often referred to as "brown grease", and is typically sent to a landfill as it is difficult to re-use.[155]

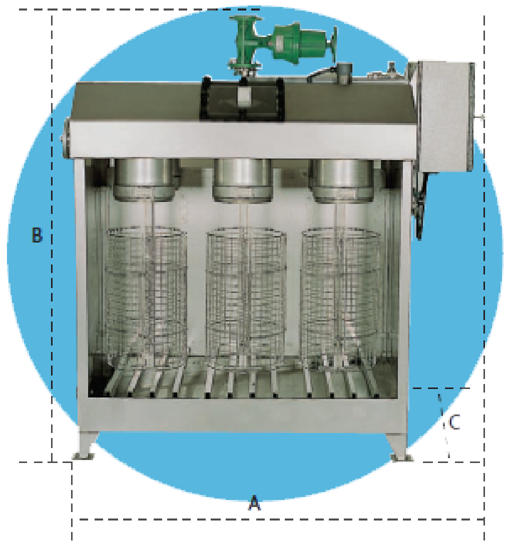


Figure 23: Sludge dewatering plant. Image courtesy Allertonuk.com.

Methane Processing

It is possible to provide heat and energy to treatment facilities by using the methane that results from methanogenesis caused by aerobic and anaerobic digestion.[156] Methane biodigesters, biogas or combined heat and power cogeneration (CHP engines) require a significant amount of space and are unlikely to be a consideration for urban facilities.

Power

MBR packaged plants have low power requirements, with aeration processes requiring about 60% of the electrical demand.[157] Most wastewater treatment plants and pumping stations are equipped with backup generators to ensure continued service in the event of a blackout. A 100,000 gpd packaged plant will typically operate a 5 horsepower blower, consume approximately 400 kW/day, and operate on 480 volts @ 60 Hz. A suitable backup generator is advised.

Tertiary Treatment

While most MBR packaged plants produce effluent that is suitable for nearly all non-potable uses, tertiary treatment may be required for specific discharge purposes, or to remove endocrine-disrupting compounds and other contaminants. Common forms of tertiary treatment involve UV filtering, chemical disinfection, microfiltration and reverse osmosis.[158] UV filtering occupies a relatively small footprint (approximately 2-6' wide by 8-10' long) and can treat up to 1 mgd of wastewater. UV filters can be retrofitted into existing plants, and lamp frames can often be submersed directly into existing tanks to further decrease footprint.

Figure 24: Trojan UV 3000 PTP 130,000 gpd self-contained installation. Image courtesy of TrojanUV.com.

Programmatic Elements

Overview

The programmatic elements required for the successful urban integration of wastewater treatment derive from two sources. A primary program must be developed in response to the functional elements and equipment required for treatment. This includes spaces for the packaged plant(s), noise and odour control, effluent testing, discharge, mechanical, and other conventional building considerations. A secondary program must be developed in response to the strategies required to overcome public aversion. These spaces predominately facilitate education, awareness, and the support and promotion of facility benefits.

Treatment Room

A 'treatment room' that contains the functional elements of the facility is required. This space must house the packaged plant, noise and odour control equipment, tertiary treatment equipment and dewatering equipment. Adequate circulation must be provided to service and maintain all systems. The membranes used in MBR packaged plants are either 'top-loaded' or 'side-loaded', often requiring additional headroom or adjacent circulation to remove and service the membrane. Auxiliary equipment and controls that operate the packaged plant are typically set on a skid system located at the head of the main aeration tank. By-products of the treatment process (grit, FOG and sludge) require room for transportation. The treatment room must be fully enclosed to ensure that the overall facility remains noise and odour-free, yet requires transparency and legibility to the general public.

Laboratory

As sample testing is an important part of the wastewater treatment process, a small laboratory is a necessary program requirement for facilities without access to a centralized testing facility. Tests include determining temperature, pH balance, dissolved oxygen content (BOD_5), suspended solid content, faecal coliform content, ammonia content, phosphorus content, nitrogen content, and chlorine contact. Tests can be conducted with relatively simple procedures such as drop count titration and color disc colorimetry,[159] requiring only a small amount of working space for instruments. Testing equipment is generally small and portable. Incubators and centrifuges require counter space; larger equipment can reside at a separate lab for more in-depth analysis.[160] A small temperature-controlled storage area (a small fridge is suitable) is required for samples. Other considerations are a large double sink and fume hood, a "U-shaped" work space, and storage for emergency equipment (eye wash station, chemical extinguishers and first aid kits).

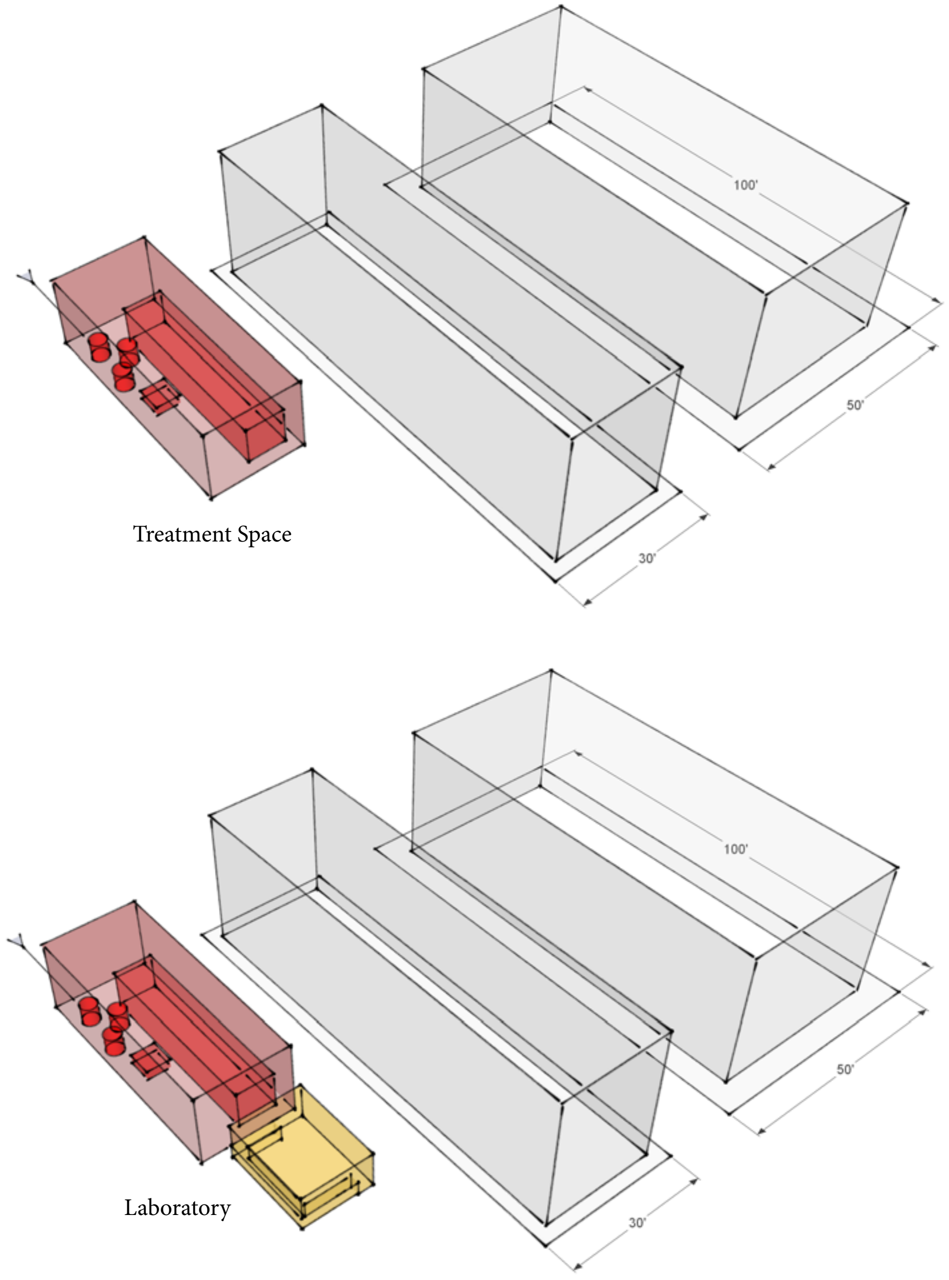


Figure 25: Programmatic spaces relative to a 30' x 100' and 50' x 100' lot w/ 30' height limitation. Top: Treatment Room. Bottom: Laboratory.

Discharge

One advantage to most MBR packaged plants is that they consistently produce effluent that can meet stringent effluent limits and almost any re-use standards.[161] This allows packaged plants to be sited away from surface water sources if required. Standard MBR plants discharge effluent that can be re-used for non-potable applications, including cooling, irrigation and greywater re-use.[162] Additional microfiltration, reverse osmosis, UV treatment and chemical disinfection processes can bring water quality up to standards suitable for potable re-use. Discharge methods should be planned in conjunction with site considerations; *Water Hospitals* sited away from surface water will require creative discharge management, and can require coordination with civil infrastructure. Sub-surface irrigation strips, water features, diversion infrastructure to pumping stations or groundwater storage, or even bottling facilities are all potential considerations for treated effluent. As nearly all CSOs occur during wet weather events, a return to surface or reservoir water is recommended.

Greenhouse

Sludge can be transportd or used on-site. On-site sludge re-use requires a greenhouse. Greenhouses are suitable areas for additional dewatering and sludge treatment through phytoremediation. Treated sludge is rich in organic nutrients and can be used for additional programmatic constructs such as composting, agricultural processes, gardening and landscaping. Approximately half of all sewage sludge produced in Canada is used as fertilizer for farm land, although the practice is a controversial one.[163] It has been demonstrated that even with emerging contaminants, sludge biosolids has potential to be safely used in greenbelts and forests after being left in the sun for 3-6 months,[164] and that through phytoremediation, sewage sludge has potential to be safely used for crop production.[165]

A packaged plant that produces 1,000 gallons of sludge during a wet weather event will require approximately 135 cubic feet of 'drying bed' room where grain polymer bags containing dewatered sludge can be stacked several feet high and left to dry. These bags can be transported by hand or in a wheelbarrow or hand truck. More than one drying bed area is advised in case wet weather events persist or occur frequently. Two 5' wide by 8' long by 3' high drying beds will hold approximately 1,800 gallons of sludge. Drying can take 2-6 months depending on temperature and desired solids percentage.

Growing beds 1' - 3' deep can be created for phytoremediation, a process where plants are used to remove trace elements of heavy metals and other toxic compounds that may remain in sludge biosolids. Examples of plants used for phytoremediation include Canadian wild rye, clover, field mustard, foxglove, as well as many other native species.[166] Remediated soil can then be transported to a third area of the greenhouse where crops and flowers can be grown. Excess manure can be transported and sold to community gardens or farms. The dewatering and remediation process allows for hands-on educational opportunities that can help the general public gain an understanding of wastewater treatment, and can easily tie with the educational component of the treatment facility.

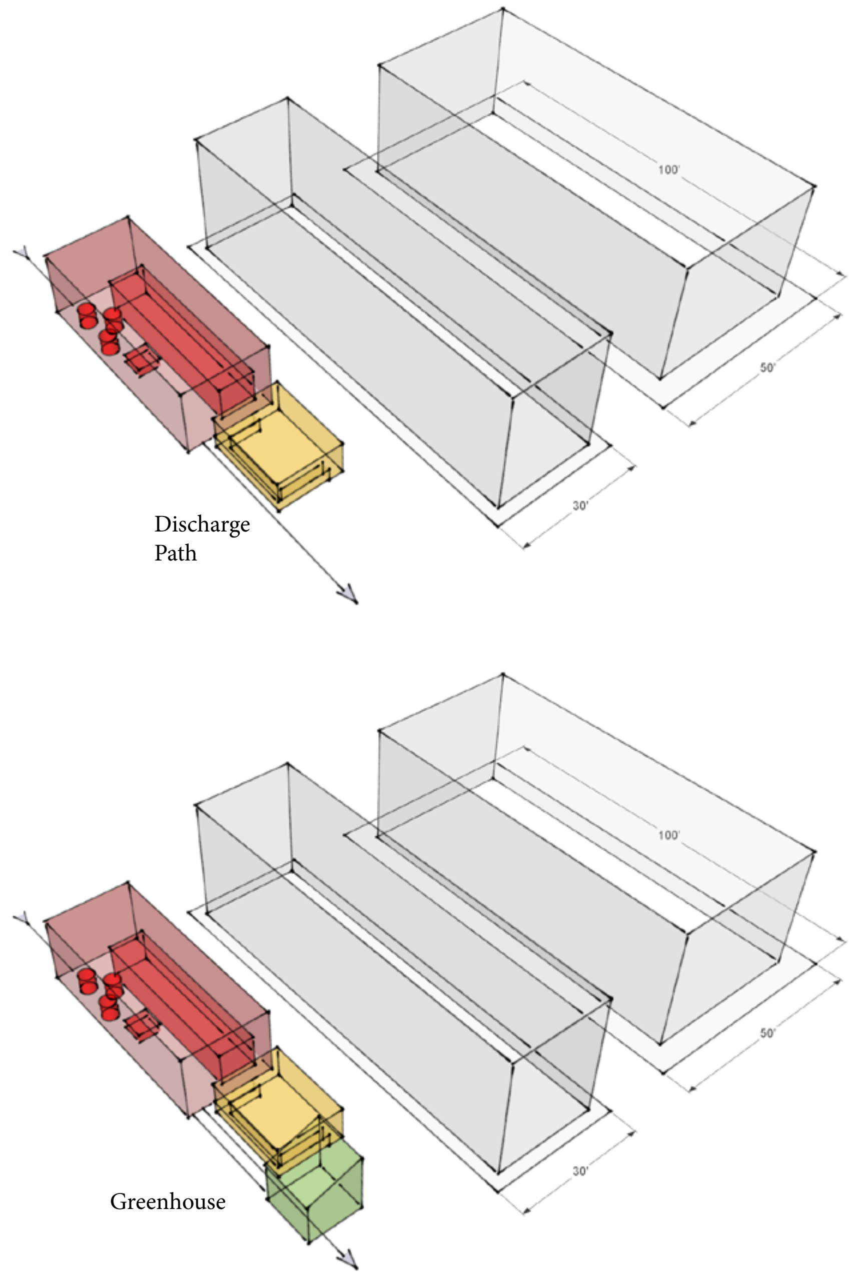


Figure 26: Programmatic spaces relative to a 30' x 100' and 50' x 100' lot. Top: Discharge path. Bottom: Greenhouse.

Education and Awareness

An educational component that brings awareness to wastewater treatment processes and systems has been shown to help mitigate public aversion to these facilities. The educational programmatic component is both important and flexible.

Direct educational components in the form of classrooms and research centers can provide education independently or in partnership with local schools, colleges and universities. Indirect educational components can generate awareness simply by creating an impetus for the public to enter the building. Provided that wastewater processes are transparent and legible, combining unrelated programs through proximity inadvertently exposes the public to the workings of wastewater treatment. If the indirect program includes the presence of public officials or experts, then trust is also indirectly fostered by the program. Examples of indirect educational programming can be as complex as libraries, municipal/provincial/federal services or community centers, or as simple as advertising space or even well-designed circulation paths.

Site programming can also foster education and awareness. Landscaping and site circulation can help the public understand how water is collected and treated within a city through creative chronological patterns. Outdoor elements such as water features, gardens or even bus stops can tie in with site design so that exposure to the treatment process occurs naturally. Nearby sites irrigated by treated effluent can also become part of the program, with public paths and access-ways becoming part of the educational process.

Public Interface

In order to ensure that Water Hospitals remain approachable, a public interface component is required to facilitate public integration. This component relates to the entry and address of the building, and can range in complexity from a front desk to a large atrium. Transparency should be employed to provide continuity between exterior and interior elements, thus encouraging the public to engage with the building. This often requires an architectural departure from private typologies (predominantly residential, office, and insitutional).

Standard Programming

Wastewater treatment facilities in Canada typically have a Group F, Division 3 major occupancy classification (low-hazard industrial), often combined with Group D or Group A occupancy for offices and support spaces. Treatment facilities are typically low-rise and sprinklered, precluding building code requirements for high buildings. OBC Article 3.2.2.82 *Group F, Division 3, Up to 4 Storeys, Sprinklered* permits combustible or non-combustible construction with standard 45 minute FRR for most spaces, and 1 hour FRR for electrical, janitorial and service rooms. Washrooms are to be designed in accordance with a pre-determined operator and visitor occupant load. Services should be relegated to a mechanical space with a relationship to the Treatment Room.

Internal accessibility between storeys is not required for Group F Division 2 and 3 occupancies, *provided* that the public is not allowed into internal areas. Accessibility is required for all

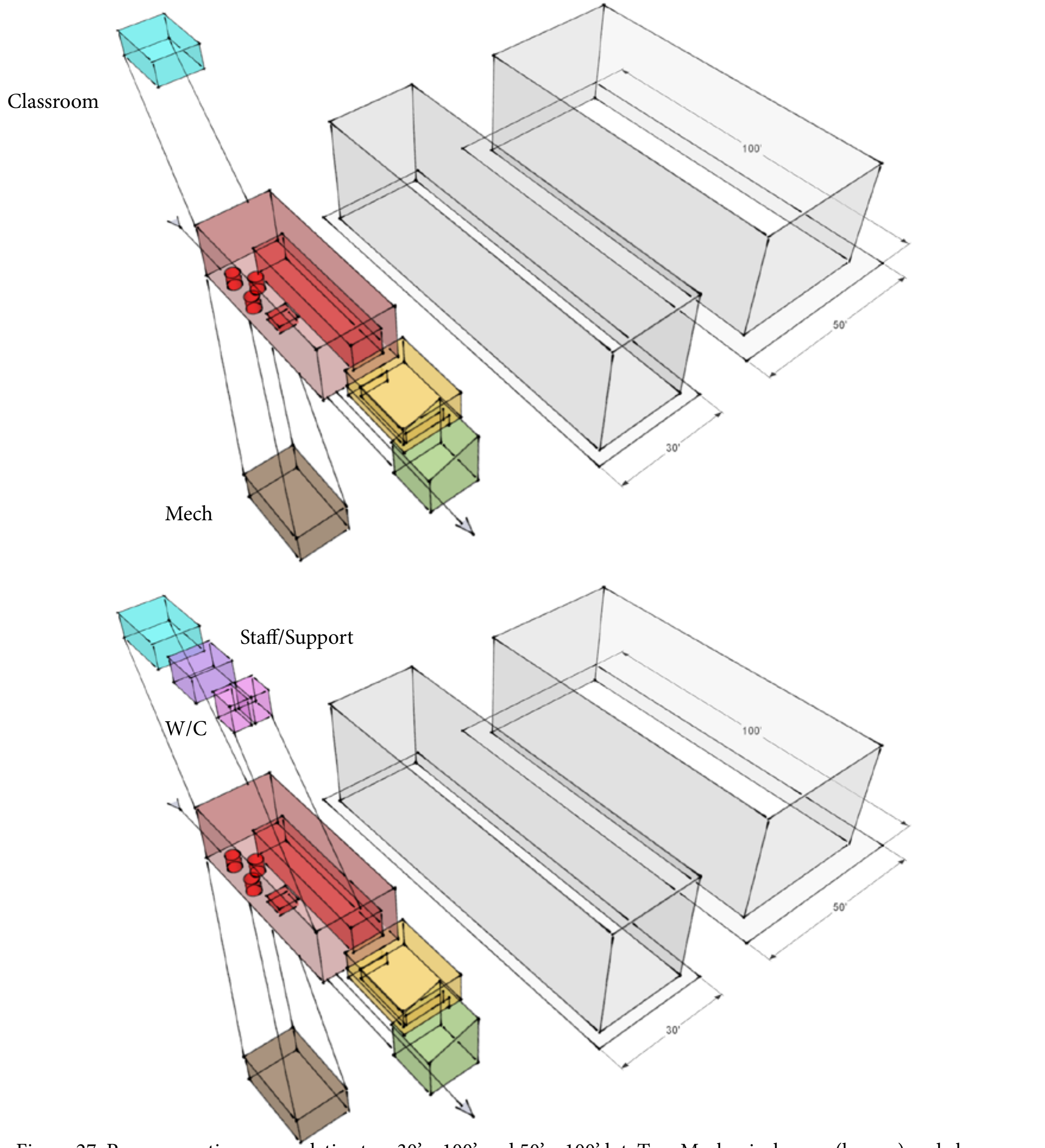


Figure 27: Programmatic spaces relative to a 30' x 100' and 50' x 100' lot. Top: Mechanical space (brown) and classroom component (blue). Bottom: Staff room (purple) and washrooms (pink).

Operation

For many MBR packaged plants, a single plant operator is needed to periodically monitor flow and equipment. Smaller plants (under 1 mgd) are often contract-operated, with an operator only needed on-site for an hour or two every day,[167] suggesting 1 FTE per 3-5 facilities. Sensors can alert staff at the main treatment facility (which often have staff on-site 24/7) to any problems that may require immediate assistance. Flow monitoring equipment can relay effluent volumes (a requirement of the *Wastewater Systems Effluent Regulations*) back to central monitoring.

Effluent testing in Canada is mandated by the 2012 *Wastewater Systems Effluent Regulations*. Full-time laboratory technicians are required at centralized facilities for daily monitoring and testing, although test frequency can range from every four hours (in treatment plants that process lethal chemicals) to once a month. Standard facilities conduct up to 50 tests daily depending on the nature of the facility's operations.[168] In a packaged plant treating wastewater, the nature of employment depends on how often the system is treating effluent. Systems that only operate during wet weather events may be able to contract out their services, or simply transport daily samples (collected by the plant operator) to the centralized plant for testing. Systems that continuously divert effluent will require consistent on-site monitoring and a full-time technician.

As an educational component is required, 1-2 employees may be required on-site to satisfy operational needs. This is entirely dependent on the specific nature of the program. Supportive spaces such as staff rooms, bathrooms and kitchens or kitchenettes are to be designed in conjunction with the operational program.

Transportation of By-products

Wastewater treatment by-products (primarily grit and FOG) can be disposed of in standard 200-litre drums positioned on skids, which weigh approximately 400-500 pounds when full and can be easily moved with hand trucks.[169] Forklifts are often used in larger facilities without spatial limitations. Dock levelers can help position drums onto light duty trucks, if the grade differential necessitates lifting. A 100,000 gpd packaged plant running at near capacity will produce approximately 1-2 drums of grit each year and 1-2 drums of FOG every few months.[170] Larger quantities of sludge, grit and FOG can require a separate holding tank that is periodically emptied with a vacuum truck. Vacuum trucks are often associated with hazardous waste and materials which have their own perceived risks, and for that reason drums and light duty trucks are a preferred option when working in highly populated environments.

Regulators

CSOs discharge into surface waterways through visually unappealing regulators and trash racks. While Water Hospitals are expected to thoroughly treat effluent to a near-drinkable quality, the imagery consistent with these sewer exits will require architectural intervention as part of the overall site, and may tie in with other programmatic elements on or off site depending on proximity.

Spatial Relationships

Due to the relatively small size of packaged plants and facility equipment, the 'Treatment Room' can potentially sit on urban infill lots 30' x 100' or larger. Programmatic spaces that maintain relationships to the treatment room (laboratory, greenhouse, and educational spaces) benefit from being on the ground floor, but are flexible enough to be relocated to second or third storeys without compromising the effectiveness of the building. Program massing shows that a decentralized, urban treatment facility can remain within most residential height restrictions.

Because of the relatively small scale of operation required for the transportation of by-products, treatment facilities can be sited on arterial or residential routes without causing undue traffic or noise to neighboring buildings.

Figure 28: Regulator. Image courtesy of Winnipegsun.com.

Urban Integration Requirements

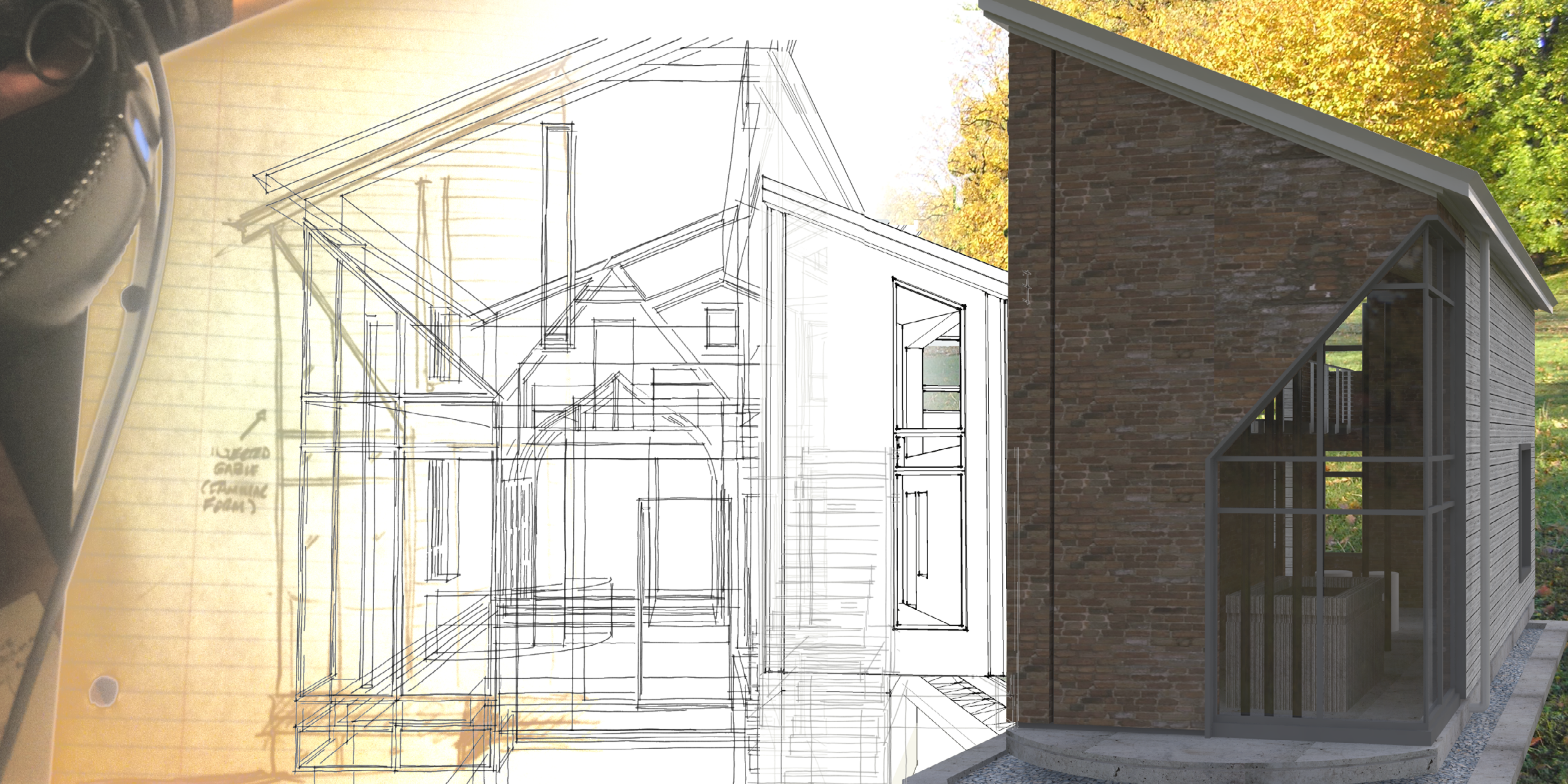
In order develop responsive architecture that will facilitate the urban integration of wastewater treatment, the research conducted in this paper has been synthesized into a list of success criteria. Functional requirements are derived from recommended systems and components. Programmatic elements are derived from the spatial needs of these systems, as well as spatial elements necessary to implement educational and awareness strategies. Site requirements have been left at a macro level within the scope and context of an urban setting. The architectural demonstration of 'Public Aversion' requirements will be further explored in the D9B portion of this thesis.

Functional Requirements	
Treatment System	75,000 – 1,000,000 gpd MBR packaged plant (gpd is dependent on CSO volume and/or population equivalent). Approximately 8' (W) x 10' (H) x 40' (L). Additional headroom or circulation space may be required to remove and service membrane.
Odour Control System	100 – 1000 cfm media drum scrubber. Approximately 2-3' dia. x 4-6' (H).
Noise Control	Double-stud walls, acoustical treatments & vibrational isolation. Additional acoustical treatment for blowers may be required.
Insulation	Building to be heated and insulated to ensure working temperatures above 5 degrees Celsius.
Sludge Treatment	Sludge dewatering package plant. Approximately 5'-8' (L) x 4'-6' (W) x 4'-6' (H).
Grit Containment	55 gallon drum(s). Approximately 2' dia. X 3' (H). Space for hand truck required. Dock leveler may be required.
Fat/Oil/Grease Containment	55 gallon drum(s). Approximately 2' dia. X 3' (H). Space for hand truck required. Dock leveler may be required.
Tertiary Treatment (if required)	UV Channels sized to MBR. Approximately 2'-6' (W) x 8' – 12' (L) x 2'-5' (H) with potential for in-tank submersion.
Structure	Appropriate structural considerations required due to heavy live loads. Packaged plant datum recommended at min. 6' below grade.
Mechanical	Part 3 building considerations.
Electrical	Part 3 building considerations + backup generator.

Programmatic Requirements	
Treatment Room – contains packaged plant, odour control equipment, noise control equipment (if any), dewatering equipment, grit and oil equipment and storage.	Area to be enclosed; process to be visible to public. By-products require disposal by light duty truck.
Laboratory	Requires fume hood, double sink, cold storage and emergency equipment storage.
Public Interface	Required for public integration. Relates to entrance.
Staff Area	Dependent on size of building and program.
Greenhouse (if required)	Required for further dewatering of sludge, or to illustrate process.
Educational component	Required to educate community, provide public awareness, and foster trust. Can be direct or indirect, internal or external.
Delivery area (if required)	May be required to transfer daily effluent samples for centralized lab testing.
Circulation	Should illustrate process and inform narrative.
Bathroom(s) Janitor Mechanical	As per NBC/OBC Part 3 considerations.
Discharge	Dependent on re-use purpose. Potable uses will require tertiary treatment and additional spaces.

Site Requirements	
Discharge	Discharge method relates to site use. Ex: sub-surface irrigation, groundwater recharge, cooling, greywater use, non-potable & potable applications have different site considerations.
Scale	Building to be designed to existing urban scale.
Pattern	Building should fit existing residential/commercial neighbourhood patterns.
Typology	Building may adopt industrial characteristics but should not adhere to industrial typology.
Electrical	Part 3 building considerations + backup generator.

Public Aversion:	
Trust	Building should appear ‘trustworthy’:
	Building should enforce normative/prescriptive behaviours;
	Materials should be understandable;
	Style should fit historical pattern of development;
	Building should appear stable and durable, with potenial for repetitive iterations.
Transparency	
	Building form should suggest nature of operation through promotion of conventional characteristics associated with wastewater treatment.
	Process should be made transparent to public.
	Technology should be made transparent to public.
Education and Awareness	
	Building should educate and increase awareness of wastewater treatment.
	Building should interact with ‘trustworthy’ groups (experts, scientists).
	Programming should educate public on the process.
	Spaces and functions should be ordered hierarchically.
	Building should delineate benefits to local community.
Form	
	Water treatment archetypes can be employed to make building recognizable.
	Positive aspects of water treatment should be denoted. Positive forms should be employed when possible.
	Negative aspects of water treatment should be minimized.


GABLE
(FAMILIAR
FORM)

Prototype

Overview

In order to test the *Urban Integration Requirements* for wastewater treatment, a prototype Water Hospital schema will be designed at the functional and programmatic level.

Site Selection

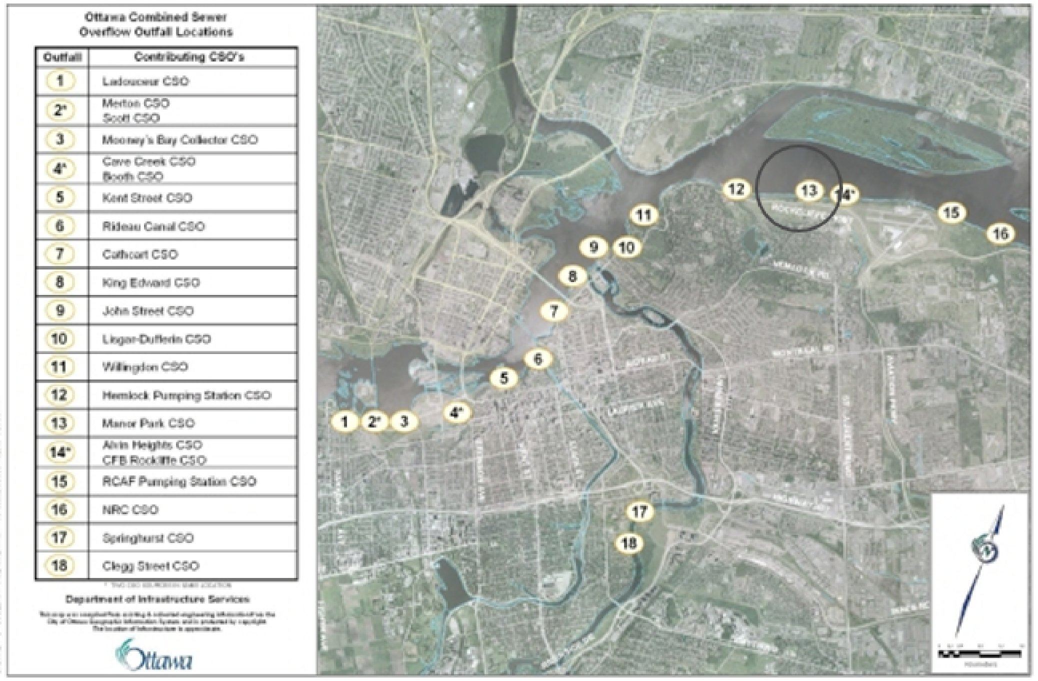
Ottawa has 230 kilometers of combined sewers, representing approximately 5% of the city's sewer system.[171] The city plans to separate two-thirds of these combined sewers as part of its *Ottawa River Action Plan* (ORAP). An *Ultimate Combined Sewer Area* (UCSA) will remain in the downtown core due to poor quality urban run-off, as well as the project being cost and labour-prohibitive within this area. The *Combined Sewage Storage Project* (CSST), another ORAP project, will address CSOs from three major regulators in the downtown core: the West End regulator, the Rideau Canal regulator, and the Keefer regulator. These regulators are responsible for a significant portion of CSOs in the city. The CSST will consist of two storage tunnels estimated to store 43,600 m^3, (considered an entire year's worth of CSOs from these three regulators.[172]) This project will cost hundreds of millions of dollars to implement. In 2014 Ottawa experienced three CSO events that significantly exceeded the tunnels' storage capacity.[173]

There are 15 additional sources of CSOs in Ottawa which are to be controlled at some point in the future through other ORAP projects.[174] Presently, all 18 regulators discharge into the Ottawa River and Rideau River. Ottawa currently experiences an average of thirty overflows per year,[175] with some regulators overflowing every time it rains.[176] Of these 18 regulators, the 8 largest are monitored, accounting for approximately 90% of all CSOs in the city.[177] The remaining regulators are not monitored. Ottawa has discharged approximately 612,000 m^3/year of combined sewage since 2006 (monitored amount), meaning that these smaller regulators are responsible for approximately 60,000 to 70,000 m^3, or 15 to 18 million gallons of sewage each year.

The City of Ottawa is an excellent locale for a Water Hospital prototype. It follows the 'classic pattern of sewer development',[178] whereby the city has a densely developed old core with combined sewers, surrounded by phases of more recent development of mixed sewer types. Combined sewer overflows and beach closures are experienced in the old development area and pose environmental and health risks. In recent years, the situation has become untenable, in that a mere 2 mm rainfall event will cause significant CSOs into the Ottawa River.[179] Limited capacity of the trunk sewer does not allow all the diluted sewage to be transported to the sewage treatment plant.[180]

Manor Park Regulator

The Manor Park Regulator is one of 8 regulators monitored by the City of Ottawa. It discharges sewage from the Manor Park residential area and adjacent R.C.M.P. 'N' Division facilities. This area is served by an old network of combined sewers that lead to the Sandridge Road Sewer underneath Sandridge Road.[181] The existing sewer is undersized, causing frequent overflows to the Ottawa River.[183] In 1999, the City of Ottawa installed flow monitoring equipment to monitor both sewer and regulator. Sewer separation projects continued throughout 2000-2010. In 2010, a new storage tank was constructed, expecting to virtually eliminate all CSOs from this site.[183] While these efforts have significantly stemmed CSOs from the Manor Park Regulator, monitoring reports from this year have shown at least six CSOs, resulting in a little over 100,000 gallons of sewage discharged to the Ottawa River.[184] This accounts for a very small fraction of overall CSOs in the city.



Manor Park is a neighbourhood in the Rideau-Rockcliffe ward with a population of 3,300.[19\85] It is an affluent, highly residential neighbourhood. The area was largely developed in the 1940s and 1950s. Manor Park has a strong community association and community council that is largely volunteer-run and is responsible for a variety of recreational programs including after-school programs, babysitting workshops, sports and fitness groups.[186] The area is highly treed and the community council takes pride in their parks.[187] The neighborhood follows a residential density pattern and residential scale, with a high percentage of single and two-storey single family dwellings sited on 50'x100' and 100'x100' lots. The area is replete with public servants and has well-defined boundaries.[188]

Figure 29 (Overleaf): Conceptual design for a small Water Hospital.
Figure 30: City of Ottawa CSO spill sites. Image courtesy of Ottawa.ca.

Prototype: Functional Requirements

Packaged plants need to be sized to accommodate the largest CSO-by-volume in order to completely treat discharge. The largest Manor Park CSO discharge since construction of the storage tunnel was 66,000 gallons on August 8th, 2014.[189] An 80,000 gpd tank would eliminate all CSOs from this site.

A 100,000 gpd P09-ESC MBR packaged plant from Pollution Control System has been selected for the Manor Park Water Hospital prototype. The plant is 40' long by 11' wide by 8' high. An additional 8' height is required to service the plant membrane from above. Effluent from the packaged plant is suitable for most non-potable purposes. Monitoring systems are located at the front end of the packaged plant and include suitable circulation space for operation. Circulation space is needed along one side of the packaged plant for servicing and maintenance.

An Allerton automatic 2-bag filler dewatering plant will dewater treated sludge into 17 gallon grain polymer bags. These bags can be transported by hand, wheel-barrow or hand truck to drying beds off-site or to a greenhouse for further dewatering. The 2-bag filler is approximately 6' long by 2' wide by 6' high. Sludge dewatering occurs within the main plant area, and is complemented by connections to transportation or a greenhouse.

A Purafil ESD drum scrubber (31" diameter and 66" high) will eliminate odours within the main tank area. A fitted cover for the tank will further mitigate unwanted smells.

By-products of the treatment process, such as grit and FOG, can be removed in standard 200-litre drums. A hand truck and lift platforms will be required to bring drums to approximately 3' above grade, where they can be conveniently transported into the back of a light-duty truck with the help of a dock leveler.

Estimated noise from the P-09-ESC blowers is 75 dBA. Double-stud 2" x 6" walls with insulation (STC 58-63) should mitigate noise concerns. Vibrational noise should be treated with mechanical isolation. Acoustical reduction boxes can be constructed around each blower for additional STC reduction. Triple pane glass and proper acoustical sealing (STC 31[190]) will help ensure a desired noise criterion of approximately NC-50 to NC-55.

In order to minimize building height, reduce floor loading considerations, and ensure that the equipment is visible to the public, the packaged plant is to be located partially below grade.

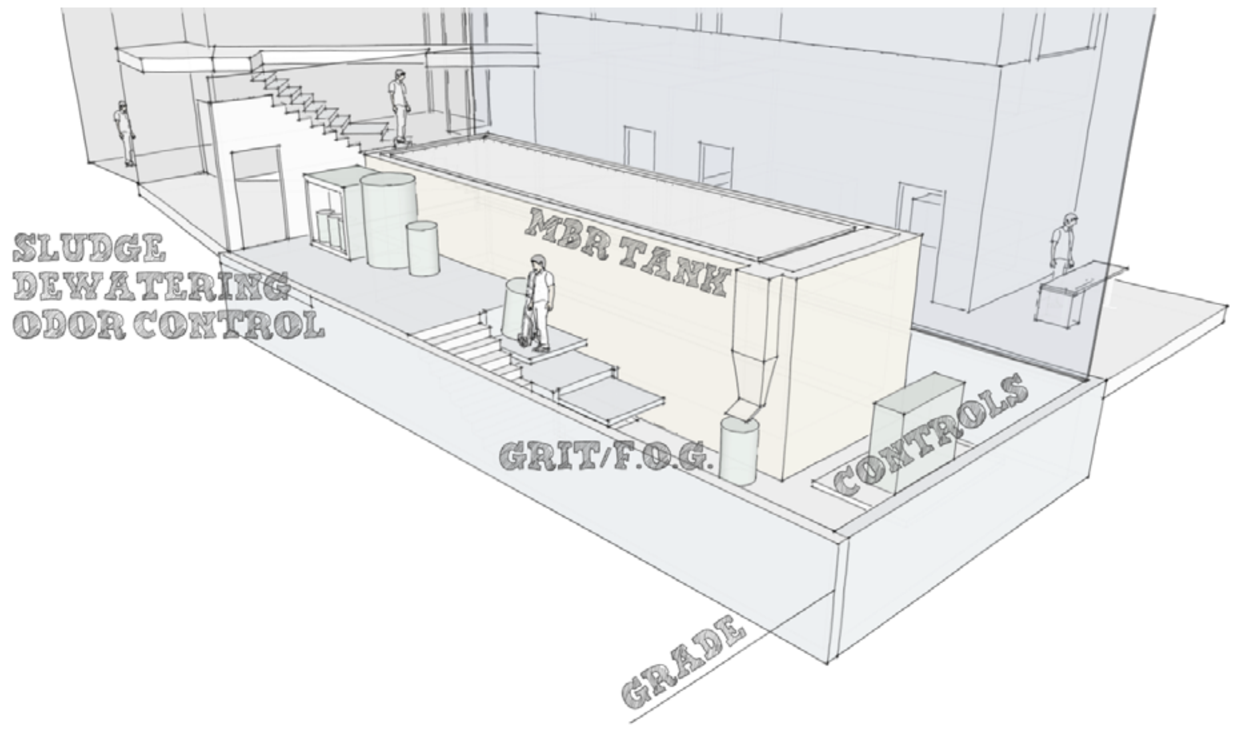


Figure 31: Functional requirements: Initial equipment organization.

Prototype: Programmatic Requirements

The frequency and volume of CSOs determine packaged plant size, which in turn help establish the required number of staff. The Manor Park Water Hospital can be managed with a contracted plant technician to monitor flow and equipment, (and ensure that by-products are safely disposed of), two part-time laboratory technicians (amounting to 1 FTE) for daily monitoring of effluent, and a city employee to interact with the public. Program requirements follow the criteria presented in *Urban Integration Requirements*, and will involve a treatment room for the packaged plant and related equipment, a laboratory, an educational component (in the form of a classroom), a greenhouse, a staff room, mechanical/services space, bathrooms and other service spaces. An entrance that serves as a public interface will also be required.

Manor Park's vibrant community organizations will be responsible for the operation of a proposed greenhouse for on-site sludge dewatering and re-use, and it is suggested that volunteers from the community become involved in part of the wastewater treatment process through gardening. The P09-ESC can be outfitted with chemical disinfection for certain heavy metals, however, local plant species known for their phytoremediation properties (such as elodea, sago pondweed and water grass) are recommended along with more brightly colored perennial variations prior to using manure for the growing of vegetables. Irrigation for plants is to be provided with treated effluent.

Proximity to the river allows for easy discharge and precludes the need for tertiary treatment. Additional uses include greywater applications, irrigation of the greenhouse, irrigation of landscaping, and water features. An architectural tie-in to the Manor Park regulator is advised.

A direct educational component will be included in the program. A classroom is proposed for use by Manor Park Public School and other interested organizations. Tours of the Water Hospital will be conducted with a focus on youth education. Transparent elements include the main control area, laboratory and greenhouse.

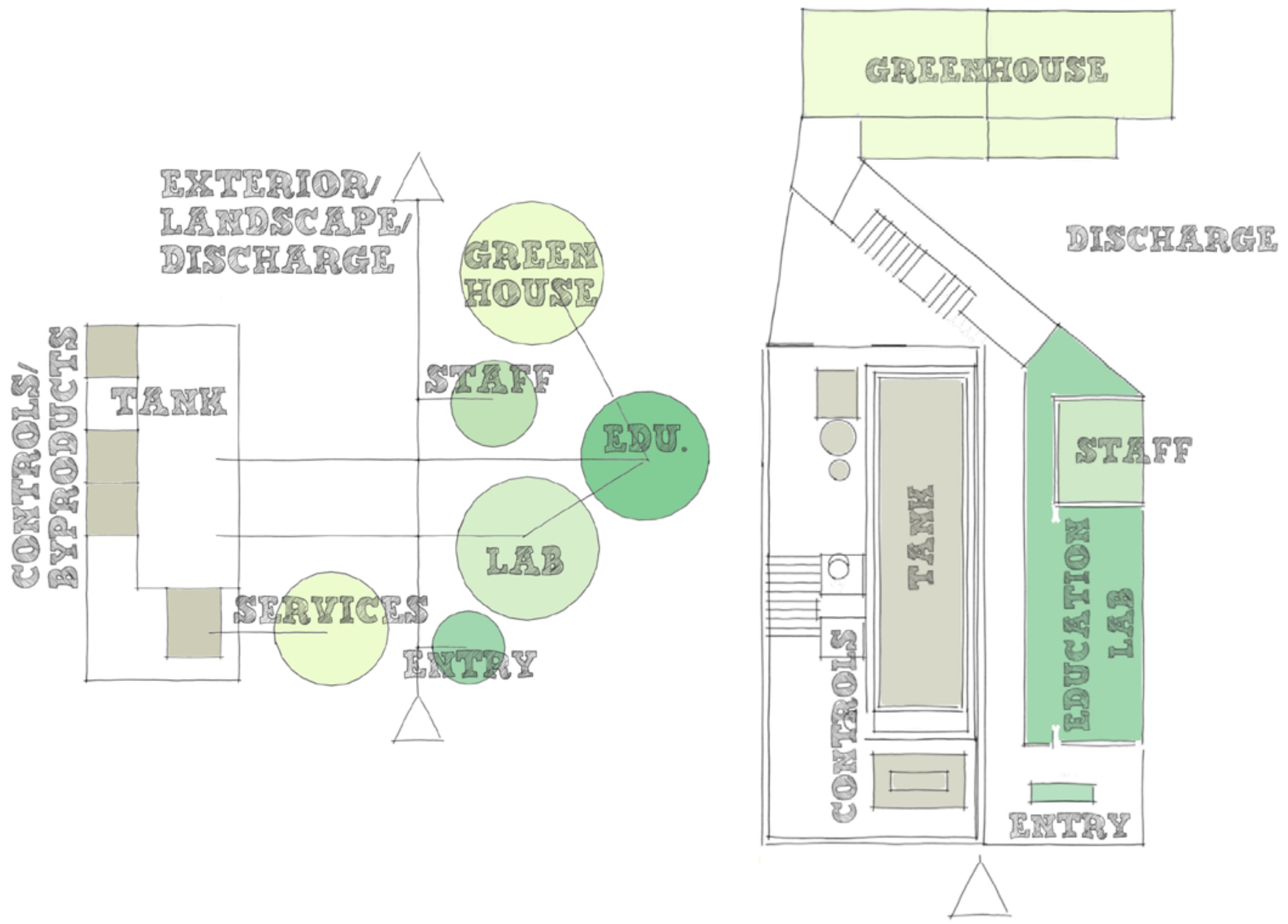


Figure 32: Diagrammatic program for prototype and program re-organization into schematic plan.

Summary

The Manor Park prototype gives form to the functional and programmatic requirements of the Water Hospital. Due to the length of the packaged plant, a rectilinear geometry with a minimum 3:1 length-to-width ratio is best suited for the treatment room, with an adjacent circulation corridor providing views within. The treatment room is best sited below grade due to height requirements. By-products are best stored at approximately 3' above grade for easy transportation into the back of a light duty truck. Between this consideration, views looking into the treatment room from adjacent circulation, and required headroom above treatment tanks, an appropriate datum of approximately 6' – 10' below grade can be established for packaged plants.

Relationships between exterior servicing and by-product transportation, laboratory and program elements related to discharge and effluent re-use (greenhouses, irrigation) are best kept at grade. Educational elements, staff rooms, and standard program elements (bath rooms, janitor, etc…) are more flexible and can be relegated to a second or third story. Mechanical spaces should be kept below grade but separate from treatment room if possible.

Functional equipment should be arranged in a manor so that the packaged plant does not block views of smaller components. Any arrangements that allow for by-products to be collected at grade should be strongly considered.

The elements and characteristics required to address public aversion to wastewater treatment processes (defined by the architectural interpretations of trust, transparency, awareness, delineation of benefits and positive form association) will be further developed through a series of design tests within a variety of urban contexts.

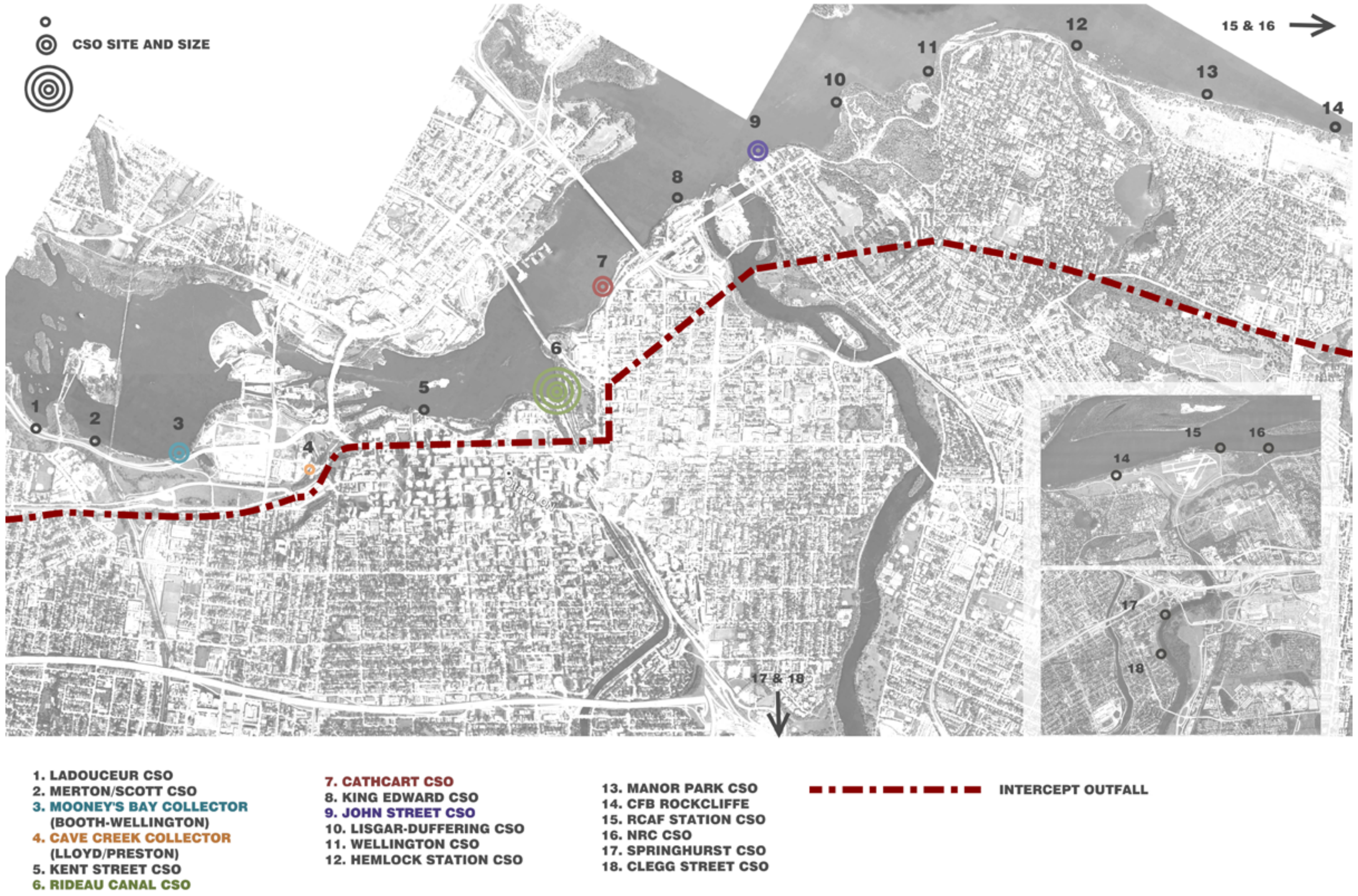


Figure 33: CSO Location and Intercept Outfall Sewer

Effectiveness

As mentioned in the *Protoype* section of this paper, The City of Ottawa has spilled approximately 1.4 billion gallons of combined sewage into the Rideau and Ottawa rivers since 2006[191]. There are 18 points within the city where these overflows occur, as is shown in *Figure 1.*

The 8 largest overflow sites are currently outfitted with real time controls that provide continuous monitoring of pipe flow data to ensure maximum capture of overflows before they occur. The captured data depicts the volume of combined sewage that overflows at each site, as well as the duration of each corresponding wet weather event.

Using 2013 data provided by the City of Ottawa, it is evident that the majority of overflows occur at the Booth Street regulator, the Rideau Canal regulator, the Cathcart regulator, and the John street regulator. The Lloyd-Preston spill site accounts for approximately 2% of all spills. The remaining 13 CSO sites are accountable for approximately 6% of all spills and are relatively insignificant.

As each spill site behaves different, the effectiveness of each urban treatment facility will also vary from site to site. Frequent spills will provide more opportunities for treatment and will increase a facility's effectiveness. Consistent spill volumes can further reduce the number of facilities required for treatment. Finally, the duration of wet weather events affects a facility's capacity. Unlike static grey infrastructure projects, dynamic decentralized facilities can continuously discharge treated effluent, allowing them to remediate greater volumes of influent provided the flow rate occurs over a greater period of time.

Successive iterations of facilities at particular CSO sites will decrease in effectiveness as the volume of combined sewage is slowly remediated. Using the Cathcart CSO as an example, a single 1 mgd treatment facility capable of storing an additional 30,000 gallons would have activated 16 times in 2013, in response to the 16 wet weather events recorded by the city. Of these 16 events, 2 produced spills small enough to have been fully remediated by a single facility. The same facility would have worked to capacity during the remaining 14 spills despite being unable to fully remediate any of them. A second facility with the same capabilities would therefore only activate 14 times, remediate 2 of the remaining spills (according to city data), and work to capacity the remaining 12 times. A third facility would have remediated another 5 spills, and worked to capacity for the remaining 7 wet weather events. In this way the effectiveness of each facility decreases until the entire spill volume is remediated.

As is shown above in Figure 3, six facilities at the Cathcart CSO location would have treated approximately 73% of monitored spills occurring in 2013. Additional iterations would have activated twice throughout the year in response to the two heaviest wet weather events, contributing a relatively small amount of treatment capacity. In many cases it may be possible for a client to identify when the value of a facility is no longer worth the cost of installation, operation and maintenance. It's important to keep in mind that the relative effectiveness of each facility changes from site to site. A facility that's only 2% effective at the Rideau Canal CSO still treats more sewage than a facility that's 60% effective at Lloyd Preston.

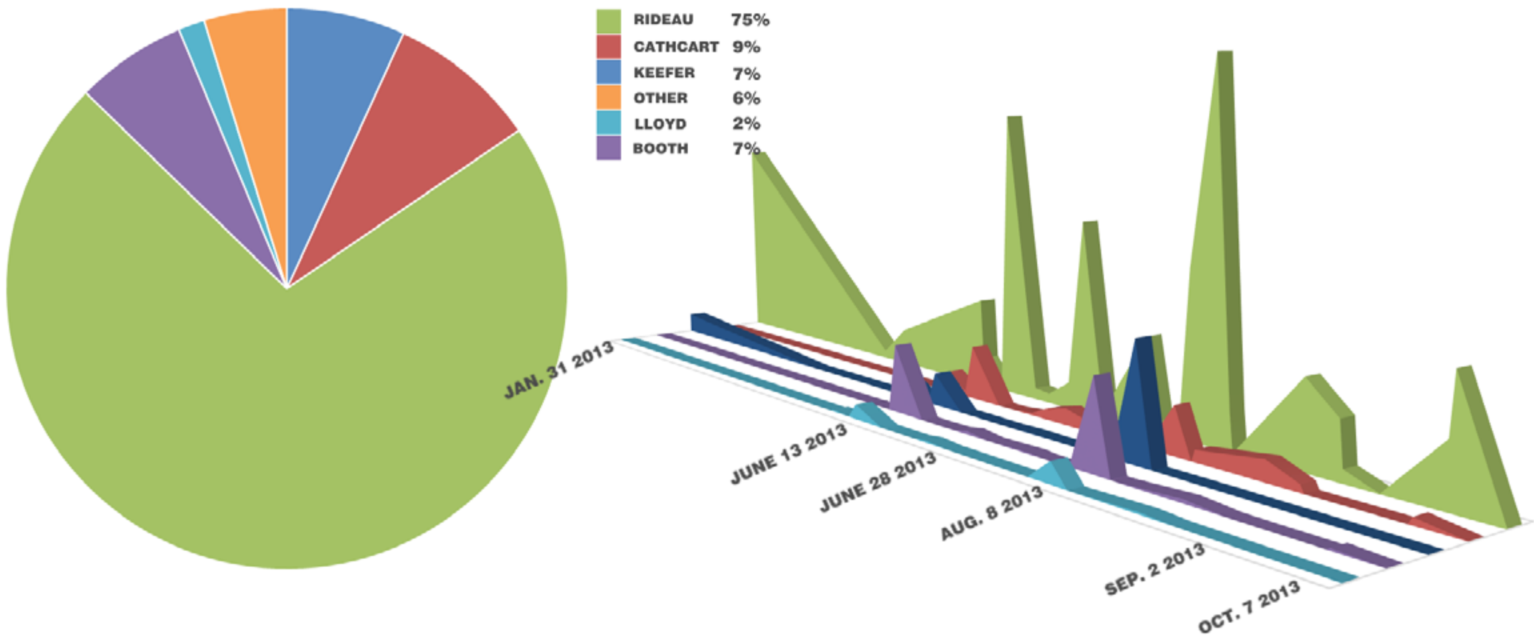
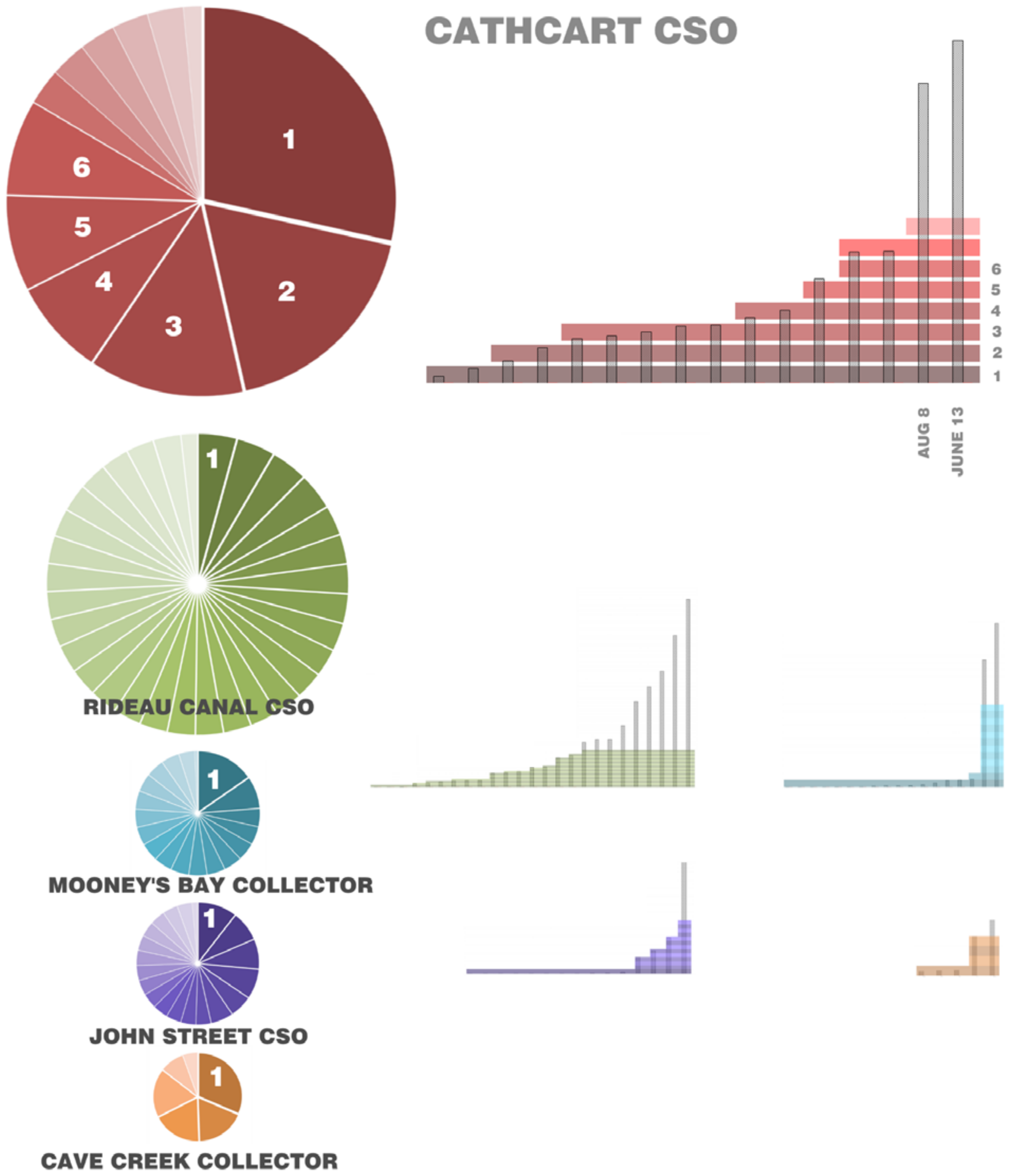


Figure 34: Distribution of spills per site, as per 2013 city data. The graph on the right shows how each major spill site behaves throughout the year. High spikes represent heavy wet weather events (the spill on August 8 2013 accounted for nearly a quarter of all CSOs that year). Discrepancies in the behavior of each spill site per wet weather event are influenced by sewer grid layout, as well as changes in the wet weather events as they occur across the city.



Understanding facility effectiveness helps determine where treatment facilities will be sited within the urban environment, as well as whether or not a reasonable number of facilities can alleviate a reasonable amount of the problem. The 13 smallest CSO spill sites can be treated with a single decentralized facility placed near the source of the overflow. The Rideau Canal CSO site would have required 20 decentralized facilities to alleviate approximately 60% of all spills that occurred at that site in 2013. This site contains some of the most highly coveted urban space in Ottawa, including Parliament Hill, the Rideau Canal, Confederation Square, the Chateau Laurier, the Rideau Centre, and a number of other Federal heritage buildings. It is highly unlikely that enough useable space can be found to implement the required amount of decentralized facilities needed to substantially alleviate the issue. In such cases decentralized models are unlikely to be a viable solution for the mitigation of combined sewer overflows. Alternative propositions may exist, such as siting facilities 'upstream' from the CSO source, thus relieving the overall system, but this solution is not within the scope of this paper.

Existing infrastructure can also constrain the location of decentralized facilities. Discharge methods depend on the severity of wet weather events. Small CSO volumes can be treated and discharged for irrigation or greywater reuse. Large CSOs will likely require discharge to surface water, as the amount of treated effluent will likely exceed greywater needs, and as irrigation during a wet weather event isn't particularly rational. In many cases, decentralized facilities will require siting between primary trunk sewers and regulators, and the actual spill site. Should these two areas be close in proximity (as in the case of the Rideau Canal CSO), finding useable space for decentralized facilities may be unfeasible. Additional localized sewer infrastructure may potentially solve this issue, but precludes the necessity for source-sited facilities, and is therefore outside the scope of this paper.

Figure 35: Each pie slice represents a single decentralized treatment facility. The vertical bars in the graph on the right represent CSO volumes corresponding to a single wet weather event. The horizontal bars represent the treatment capacity of a single facility.

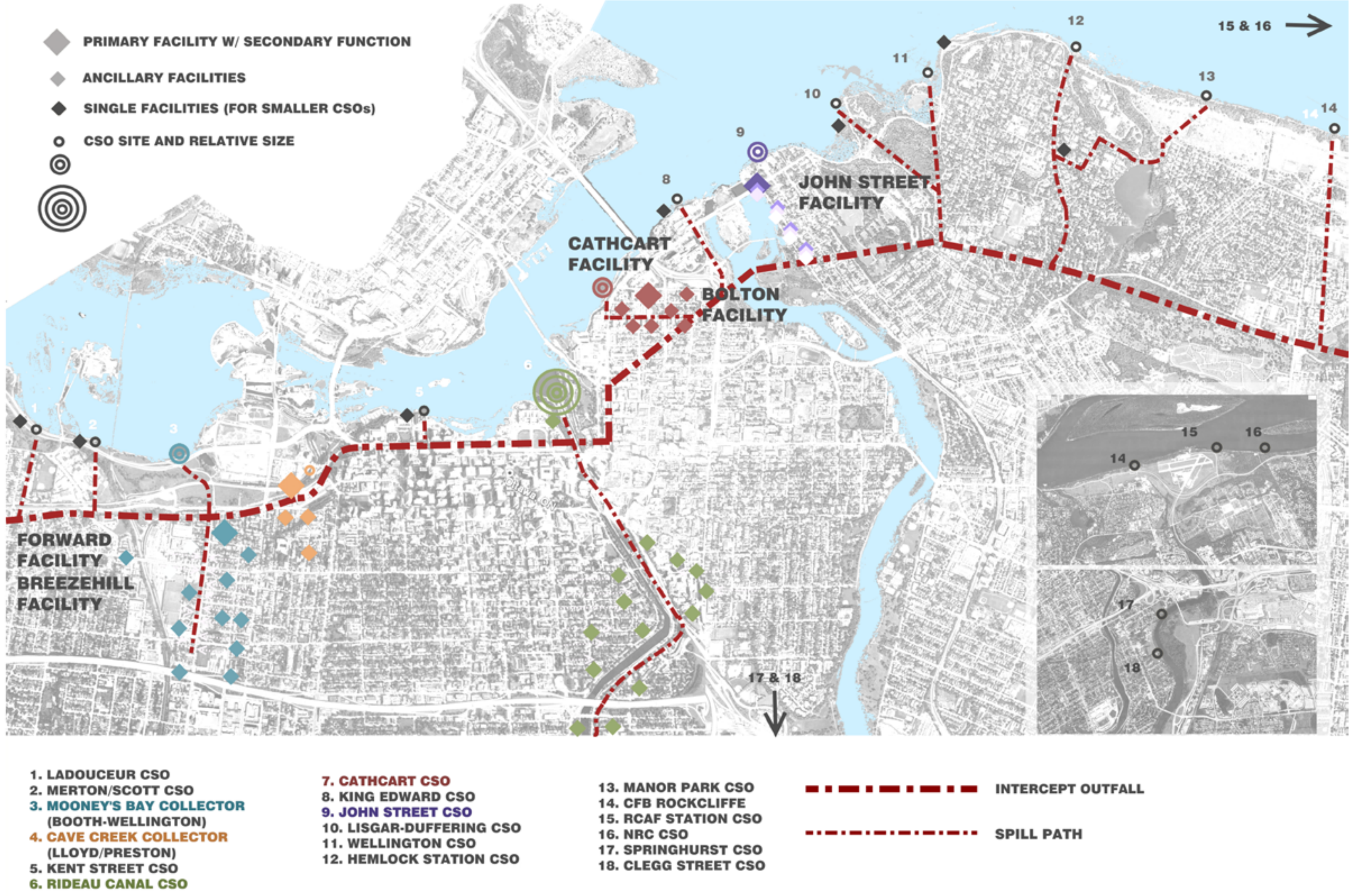


Figure 36: Potential facilities are identified for CSO spill sites in Ottawa. East of the Rideau River the Intercept-Outfall sewer pulls away from the Ottawa River, providing several opportunities for source-sited decentralized treatment. It should be noted that these locations represent a very small percentage of total spills in Ottawa and require few facilities.

Cathcart Lead Facility

To test and demonstrate the architecture required for a successful urbanized facility, a CSO with ideal spill characteristics and a highly visible urban site has been chosen. A 1 mgd MBR decentralized facility will be located in the Bytown (Lowertown) neighborhood to help alleviate the Cathcart CSO. The building's program will follow recommendations made by the D9A module and include a treatment space, small laboratory and support spaces, as well accommodate civic functions requested by the community. The Cathcart treatment facility will act as an ambassador building that provides an opportunity for Lowertown residents to familiarize themselves with the concept of urbanized wastewater treatment, preparing them for future iterations within their immediate neighborhoods.

Figure 37: Cathcart Lead Facility site plan. Top left: Context map showing the Bytown Market relative to the City of Ottawa. The yellow dashed line represents Ottawa's Intercept-Outfall Sewer. Top right: The North-West quadrant of the Bytown Market. Bottom: Bingham Park, bounded by Catherine Street to the South, Bolton Street to the North, and Parent Avenue to the West. The existing parking lot is the determined site of the Cathcart Lead Facility. A variety of mixed-use urban space surrounds the site, including residential, commercial and institutional ventures. Several embassies, government facilities, and a hospital also punctuate the immediate urban fabric.

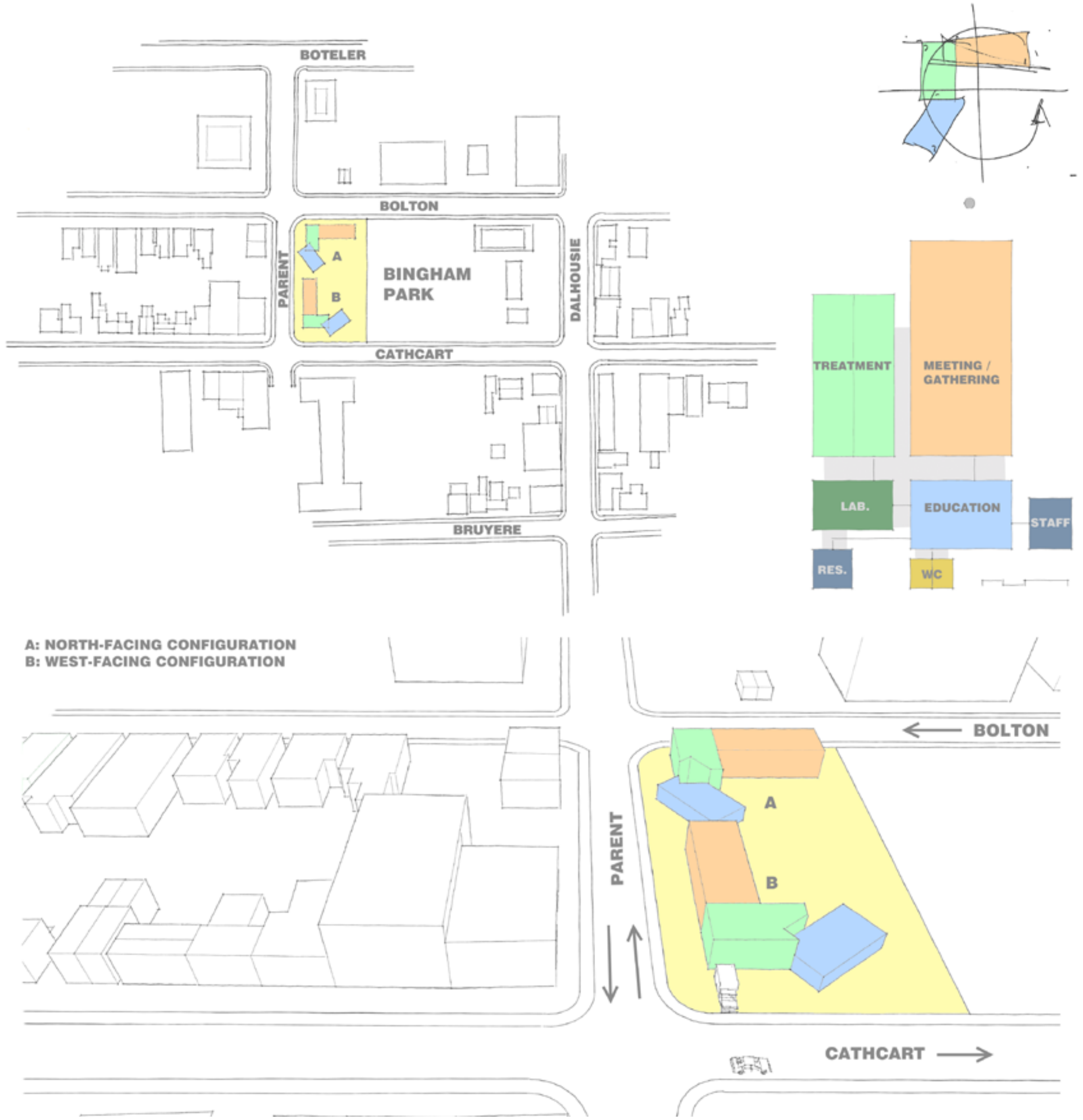


Figure 38: Basic programming and potential site orientation. Two proposed configurations are tested to determine ideal orientations for primary and secondary programming. The West-facing orientation is preferred as it connects the main treatment space with Cathcart Street (a busy street suitable for transportation purposes). The municipal (meeting/gathering) component is set along the only two-way street that bounds the site and gives the 'front' of the building the most visibility. The West-facing orientation also places the educational component closer to the adjacent park, offering an opportunity for nearby residents to engage and learn about the building.

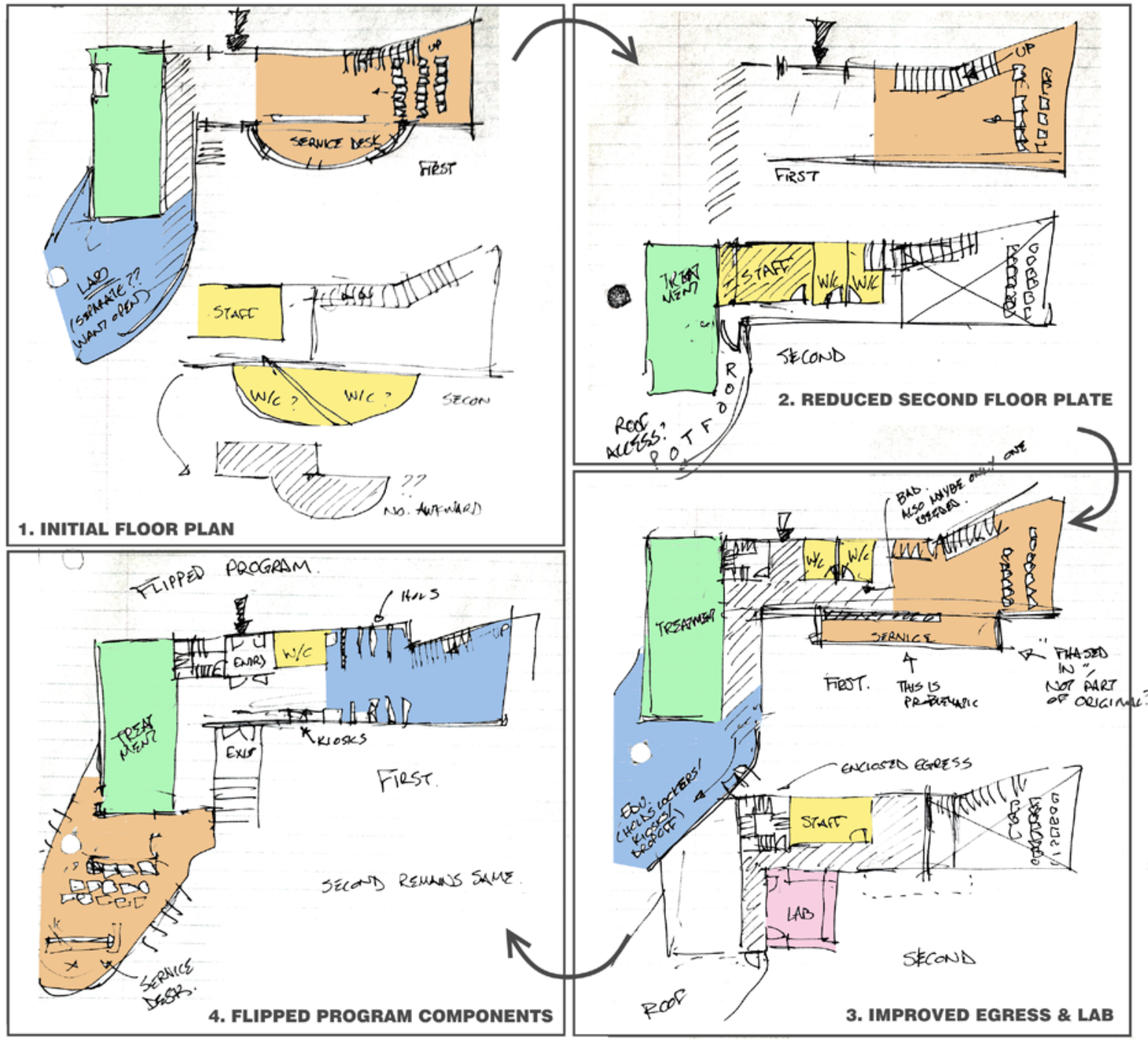


Figure 39: Schematic development and resolving program spaces. The bottom left image ends up being the strongest schematic layout despite flipping primary components. In all cases, the treatment space remains centralized to the building plan, giving it visibility along both axes, and providing views from several vantage points within the building. The municipal component now requires visitors to walk past the treatment space to reach a Service desk, creating an impetus for indirect engagement and education. Ottawa Public Library holds lockers and drop-off boxes are in line with facility equipment and create a pleasing environment to the immediate left of the entrance.

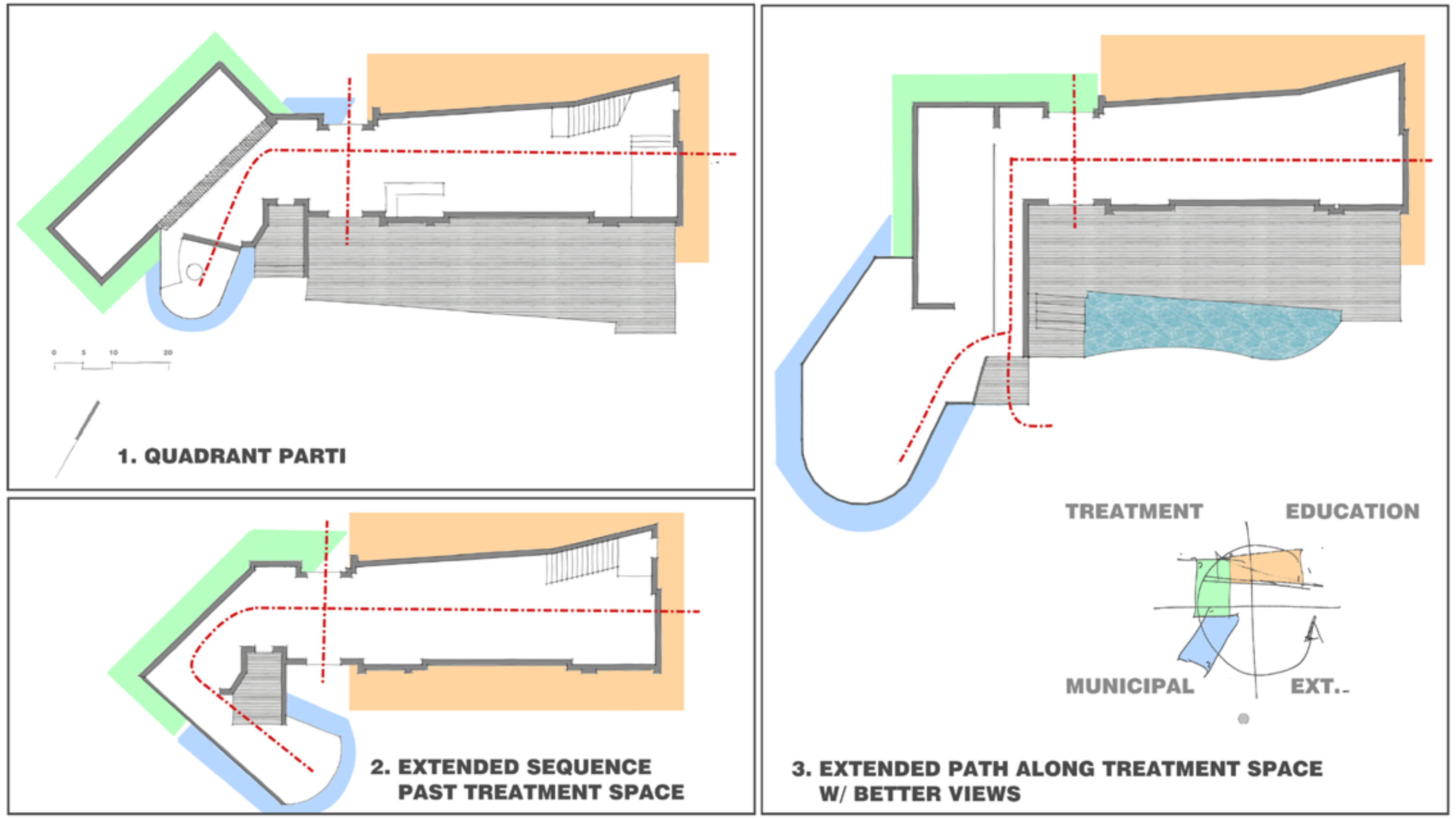


Figure 40: Circulation development. With the program flipped, a quadrant parti is used to optimize long, linear circulation routes that offer specific choices to visitors. These circulation routes are curated in a manner that brings visitors close to the treatment process, as well as to spaces for enlightenment, engagement and reflection. Exterior and interior circulation paths intertwine to help blend interior and exterior functions, a common practice in architectural transparency used to encourage visitors and neighbors to appropriate the building.

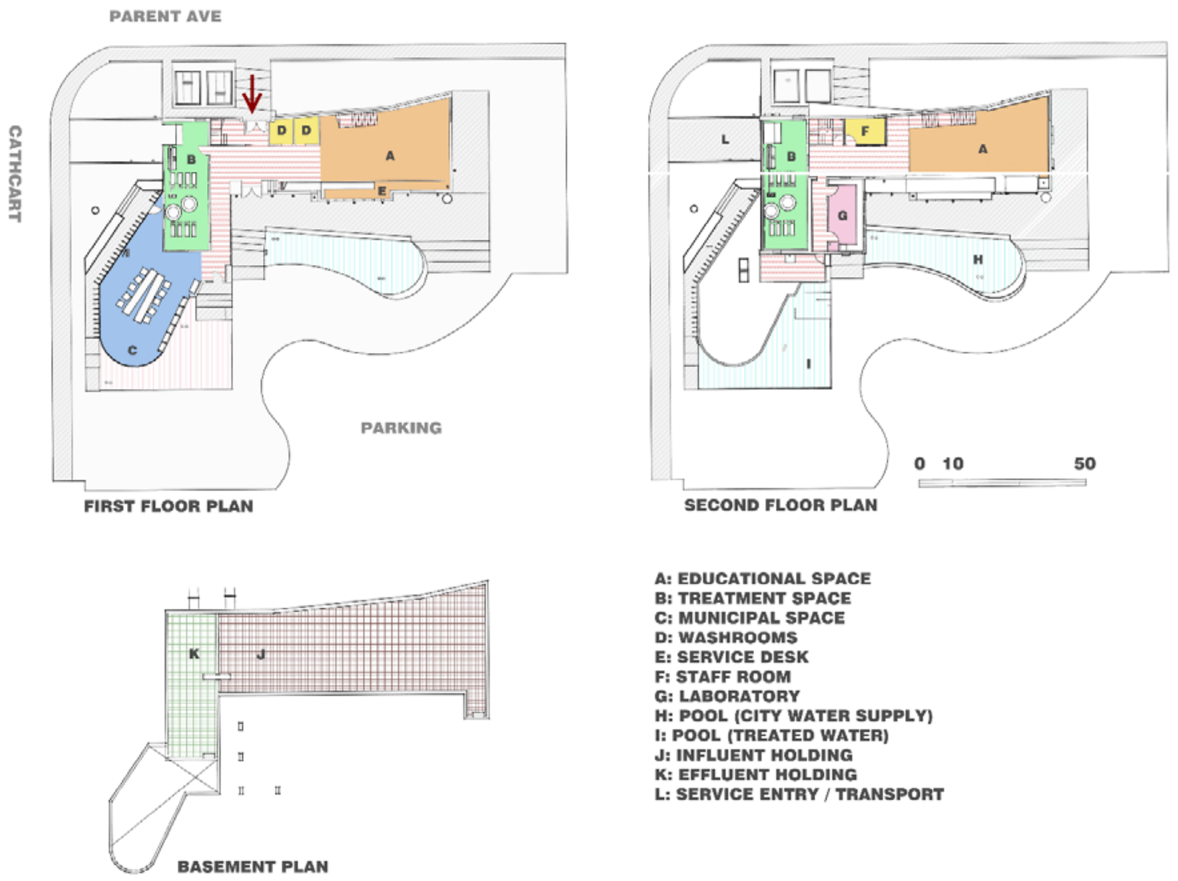


Figure 41: Plan Development. Initial design development. A variety of issues exist with this layout, including awkward washrooms, egress, natural lighting, and furniture layouts.

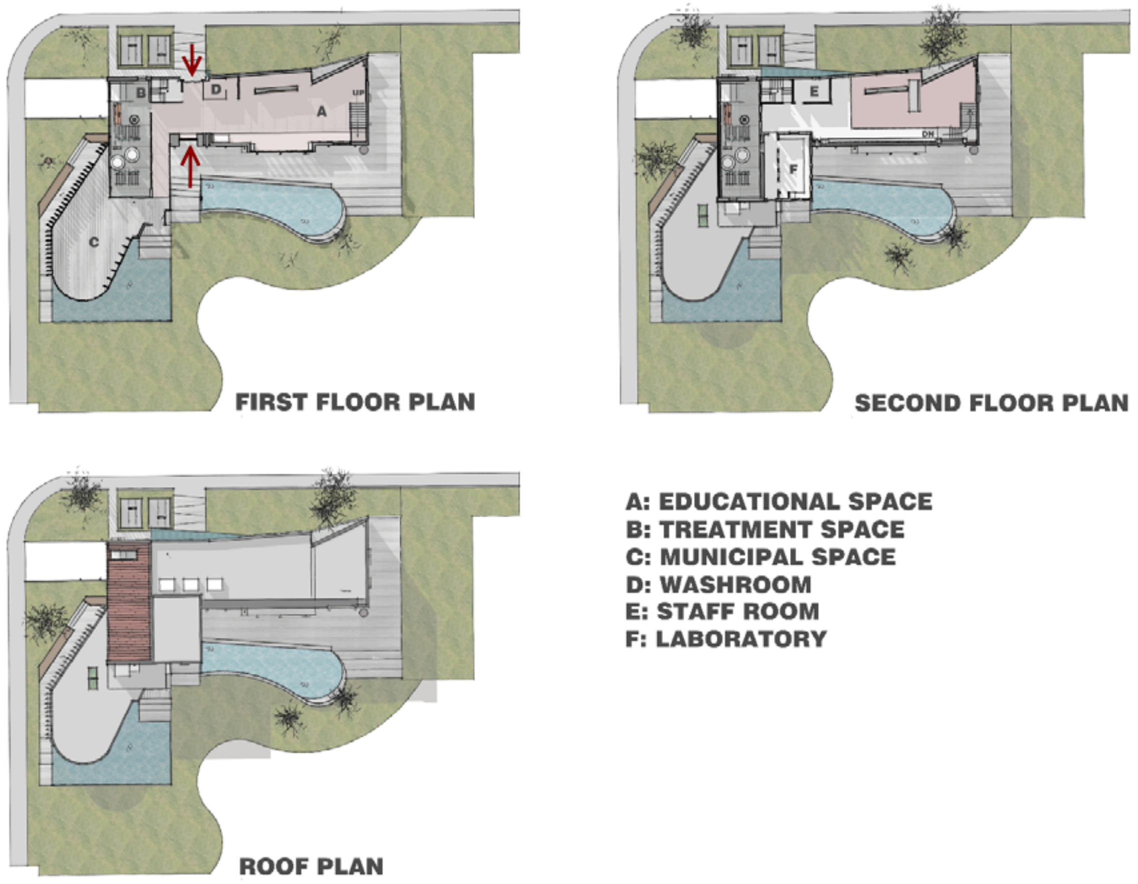


Figure 42: Plan Development. Development and refinement have resolved many of the building's preliminary issues.

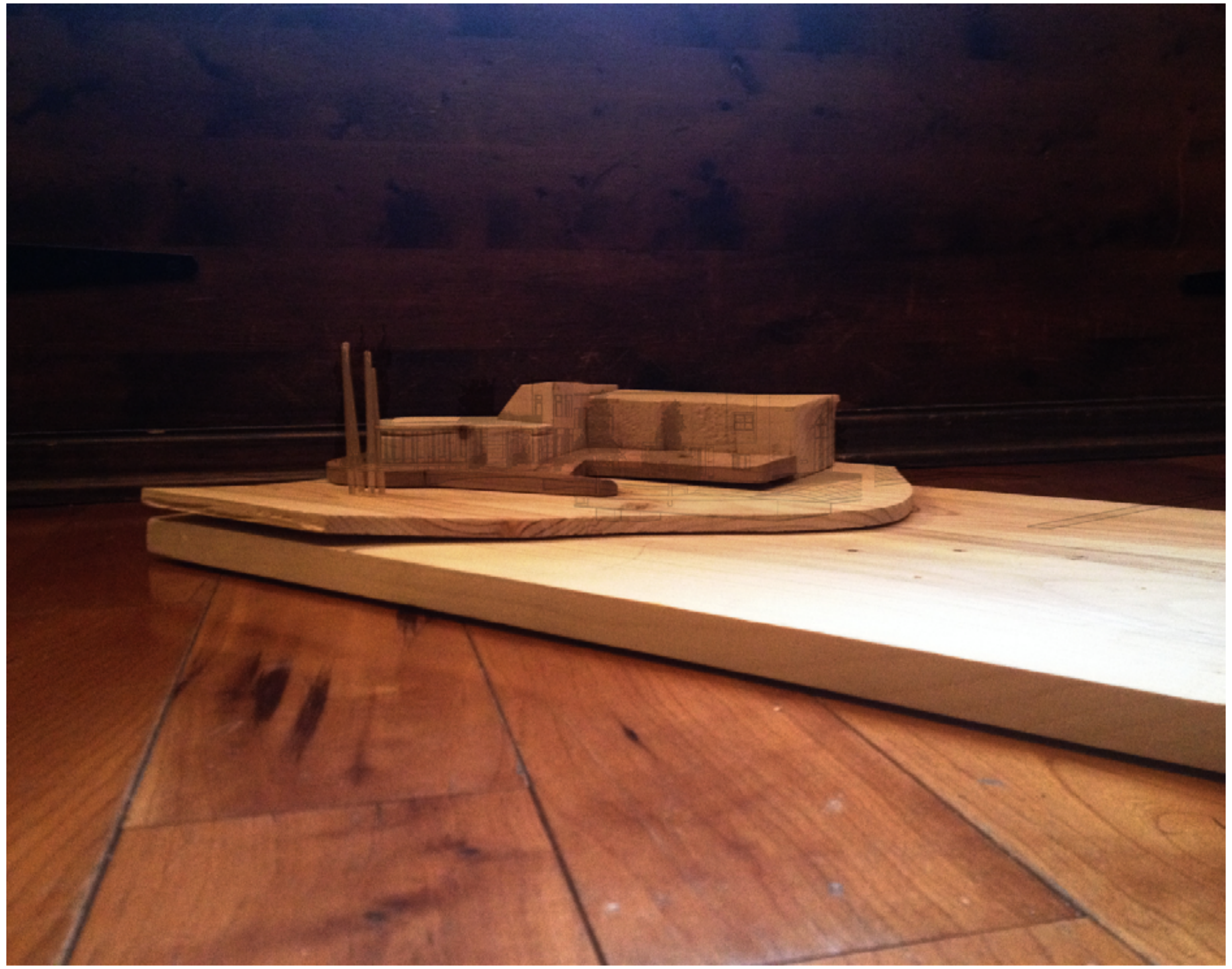


Figure 43: Massing model of the Cathcart Lead Facility.

Research conducted in the D9A module posits that direct and indirect interaction with the facility is paramount in positively adjusting public perception towards the building. This interaction is made possible through the merging of a secondary program that encourages people into the building. Needs identified by the community include community rental space, indoor walking space for the adjacent hospital, a Service Ottawa outlet, and holds lockers for the Ottawa Public Library[192]. Educational and municipal program spaces were developed in response to these requests, resulting in the presence of authorities on-site (a useful strategy for improving trust) and an educational space where risk perception can improve through heightened understanding and awareness of the building and its function.

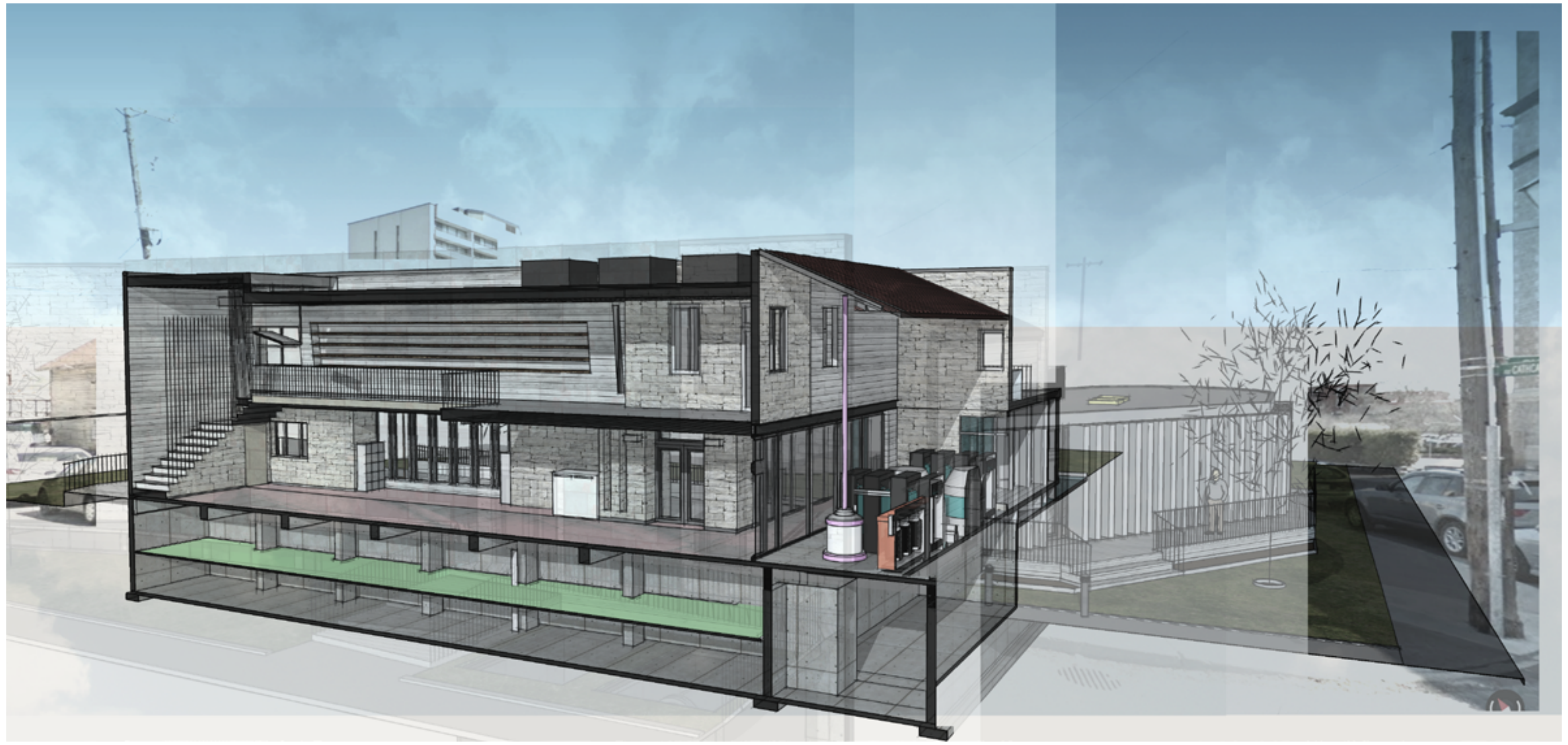


Figure 44: Section development and views to the treatment space.

The Cathcart Lead Facility demonstrates risk mitigation strategies identified in D9A through the following architectural interventions and characteristics:

- The 'front' face of the building (west elevation) depicts a civic architecture: institutional materials and proportions are organized in a classic "central block with wings" massing common in historically trusted commercial typologies[193]. Openings along this façade are heavily controlled and strictly positioned to frame views of treatment equipment, disassociating the building type from modern commercial ventures. A strong, static, rectilinear geometry and heavy 2'x4' stone and copper modules help convey a sense of value. The west elevation is the most visible side of the site due to two-way traffic along Parent Ave. , allowing the building to be immediately identified as building type that is neither residential nor commercial. Industrial buildings often lack architectural intervention, precluding the urban treatment facility from being lumped with the industrial type.

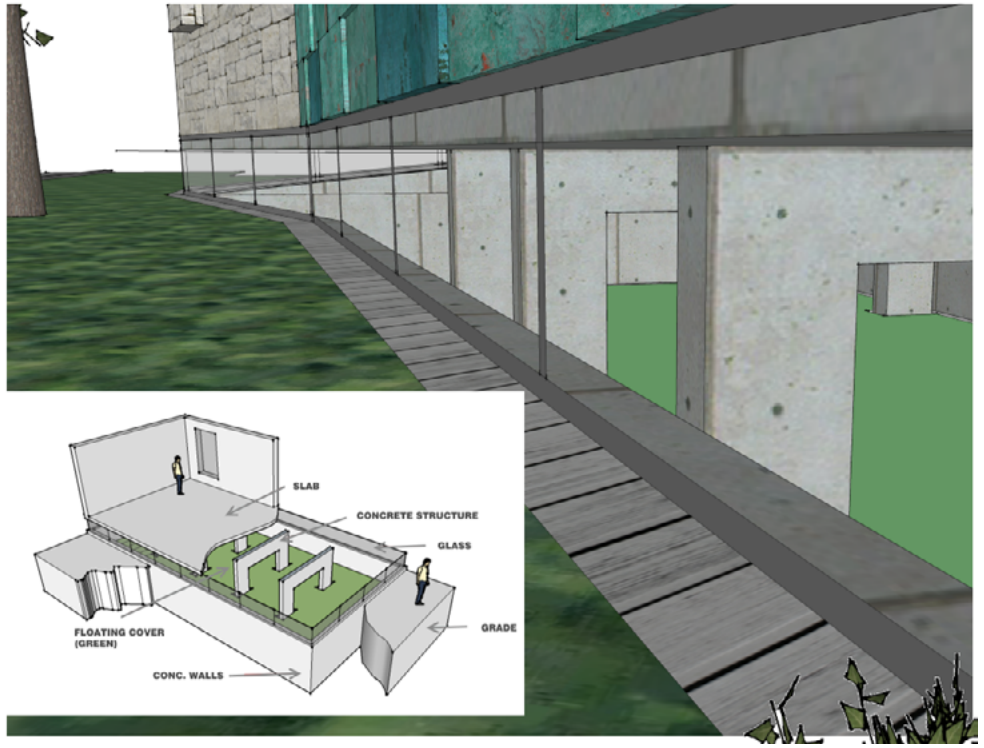
- The building partially responds to its immediate context by respecting setbacks, height limitations, and the requirements of a heritage overlay that's part the neighbourhood's zoning requirements. The stone ashlar pattern, rough sawn face, and slightly oversized module mimics the materials used by the adjacent hospital. This visual association makes the building appear to older than it actually is. The visual break along the south end of the block suggests the building has been added to over time. This further reinforces the notion of preservation – a concept that reinforces the idea of value and significance.

- The decision to use copper panels stems from a number of considerations. Copper is a familiar material in Ottawa that is routinely associated with the roofs of provincial and federal buildings. The panel size (2'x4') is larger than most residential modules, but smaller than much of the institutional work seen within the city. The material ages and responds beautifully to changes in the weather and helps convey the concept of a living building, and the blue composite tint is a natural choice for a function that relates to water.

- A basement detail along the west façade lifts the building up and cantilevers the ground floor slab out to the envelope. A narrow band of glass offers a view into the tanks below grade, demystifying much of the work that often occurs underground in civil infrastructure projects.

- The treatment space itself is contained in a half gable volume consistent with many of the residential masses in the immediate neighbourhood, demonstrating flexibility. The volume is flanked by two heavy stone walls that tie in with the rest of the architecture and help denote phasing and preservation. Openings within the treatment space are kept at humanistic, manageable scales. Windows are focused on interesting aspects of treatment equipment. An overhead door is scaled to residential proportions to prevent an industrial look. A recessed dock leveler allows light duty trucks (vacuum trucks are undesirable in urban neighborhoods) to back into the building at grade and remove excess byproducts in a very discrete and sensitive manner.

- Byproduct removal occurs along Cathcart Street, a busy route suitable for light traffic
- Landscaped banks along the Cathcart façade provide planters in which treated, dewatered sludge undergoes phytoremediation. Nearby signs explain the process and provide a safe means in which the public can become more familiar with the treatment process and its by-products.



- The facility's east façade faces Bingham Park. Exterior circulation paths curve around the property in a controlled, linear fashion that gradually introduces people to the building's function. Exterior educational advertisements describe the benefits of the building while tangible examples are arranged around the viewer as they move past the building.

Figure 45: Foundation detail.

Figure 46: A: Selective views into interior equipment. B: Major sewer infrastructure leading in and out of facility is revealed. C: Exterior views to treatment space. D: Interior lighting at grade. E: Treated effluent pool vs. City water supply pool. F: UV treatment detail. G: Interior views along treatment space with room for educational posters above.

- A municipal space floats above a small pool with a riverstone bed. The pool contains treated water from the facility's operation. The pool demonstrates that the water exiting this building is healthy enough to become a featured component of the building's design and landscape. The pool fills and empties with the wet-weather events that the facility helps remediate, denoting a strong connection between weather and waste. A small wooden platform at the end of a corridor adjacent the treatment space allows guests to come into direct contact with the pool and test their comfort level with treated effluent. Visitors may simply look and reflect, or dip their fingers or toes in the water if they're brave enough. This helps dispel the perceived health risks with treated combined sewage.

- A second pool at the north-east corner of the building is filled with treated water from the city. The two pools allow visitors to make their own comparisons, and understand that there is very little difference between treated effluent, and water treated by the city's filtration facility.

- An interior circulation path adjacent to the treatment space is open on either side so that colour-coded equipment is visible from nearly all points inside the building, as well as from the exterior park, the parking lot, and the rear deck. Additional openings are selective and in most cases prominently showcase specific parts of the building's function.

- The main entry and exit are close to one another, reassuring curious visitors that they can quickly appropriate the space, as well as exit the building quickly should they find it uncomfortable.

- Heavy glass panes in line with the ground plane briefly reveal sewer infrastructure as it enters and exits the building, providing an element of transparency.

- Interior and exterior educational material are prominently displayed throughout the building. Space for educational advertising becomes part of the design programming.

- A number of smaller considerations help the visitor engage with the process: a farm pump at the entrance allows people to pump out treated water; the number of treated gallons of sewage is prominently displayed by interior marquees to delineate building benefits; and colour-coded elements and signage help identify the process.

Figure 47: The East Perspective, facing the park, provides an intriguing and comprehensive view of the facility. Spaces such as the laboratory and municipal component have been designed to appear to have been 'added on' in later stages of the design.

Figure 48: The South Perspective shows the treatment space bracketed between heavy stone walls, re-interpreting the residential typology while expressing flexibility.

Figure 49: The North Façade remains a heavy mass with long exterior views to treatment equipment.

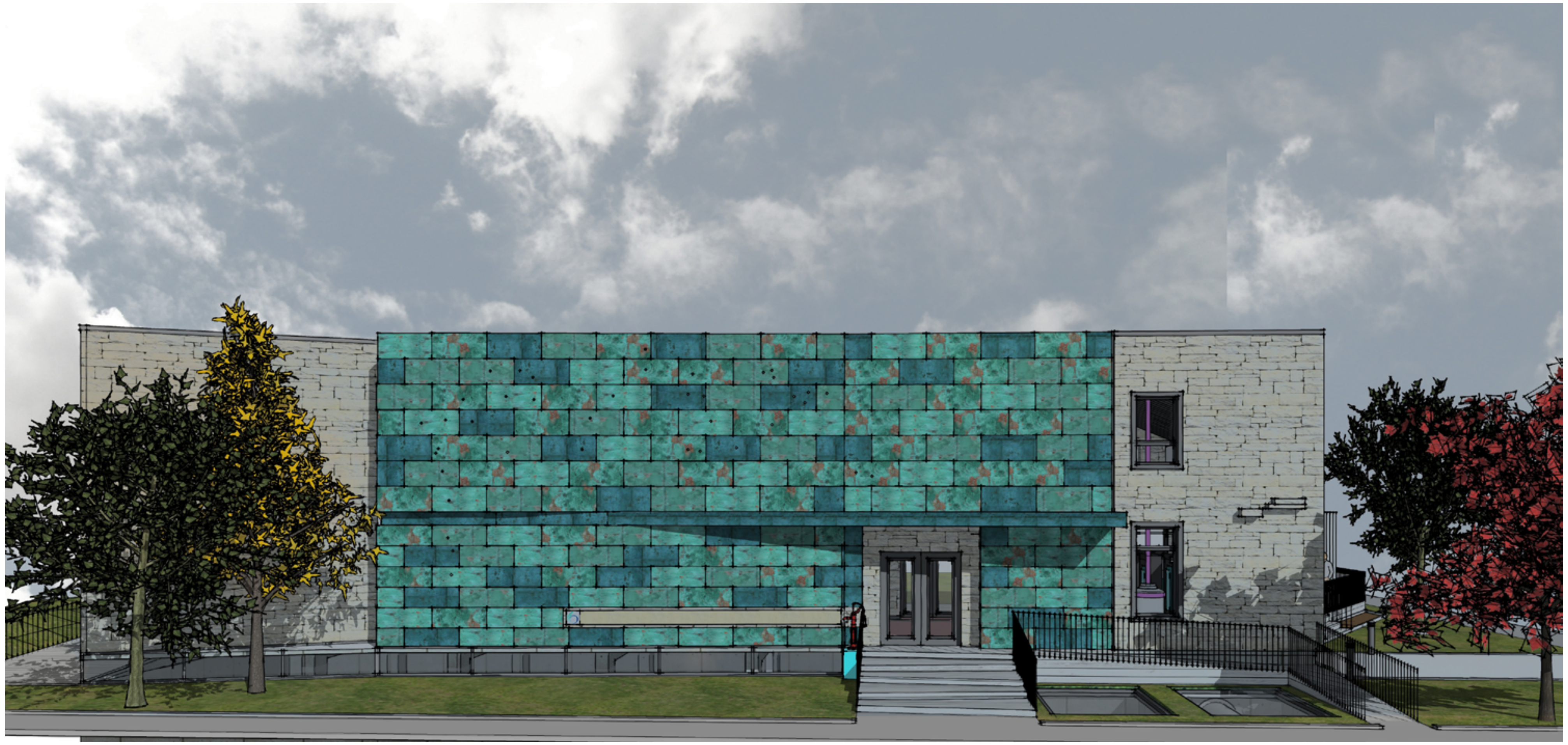


Figure 50: The West Perspective shows a strong rectilinear pattern in stone and copper atop a number of details that open the building's function to the public and allow it to be appropriated.

Lead and Complimentary Facilities

The Cathcart Lead Facility would have treated some 1.39 million gallons of sewage in 2013, or approximately 27% of the Cathcart CSO. As additional facilities are required, an examination of the relationship between the 'lead' facility and successive complimentary iterations can help understand how the architecture of a facility responds to changes within the building's program and site. Close proximity between facilities (due to sewer infrastructure constraints) precludes the necessity for similar secondary programming at all locations. As an example, it will not be necessary for all five subsequent facilities treating the Cathcart CSO to possess holds lockers or City of Ottawa service counters. Auxiliary facilities therefore must shed redundant program components, while still identifying as a decentralized urban treatment station. This is still principally accomplished through the demonstration of architectural strategies discussed in module D9A. However, as some risk mitigation strategies are no longer able to leverage the benefits of secondary programming (education, awareness, etc...), they must present themselves within the architecture of a "stripped down" facility, whose base constituents essentially encompass a treatment space with a service entry for transportation of by-products. Auxiliary facilities can realize this by discernibly complimenting a lead facility, strengthening their self-identification through visual relationships.

Characteristics and Context

Architectural characteristics refer to distinguishing features that constitute or indicate the character or peculiar quality of a building. Characteristics that persist through various iterations of a building type often indicate typology. To identify persistent characteristics, a number of facilities must first be designed in response to a series of different contexts. These facilities will employ the same functional and programmatic requirements, incorporate the same risk mitigation strategies, and will respond to the same design questions. By analyzing the resulting architecture at a categorical level, commonalities (if any) can be readily identified and used as criteria to aid the design of potential urban treatment facilities.

Figure 51: Attempts to create facility design models in a variety of urban neighborhoods and contexts.

Bolton Complimentary Facility

The Bolton Street Complimentary Facility is sited along Bolton Street in the Byward Market, a few blocks from the Cathcart Lead Facility. The Byward Market neighbourhood contains mixed-use residential, institutional and commercial typologies. A number of embassies preside along the Sussex Drive Ceremonial Route as well as throughout the immediate neighborhood. The typology of the Byward Market neighbourhood is varied enough to permit some flexibility when it comes to building type and acceptance. Nearly two-thirds of all residences in this area are rented.

The complimentary facility's form responds accordingly to the architecturally-driven buildings that surround it. The building's longitudinal axis is set so that the front façade does not overwhelm the street edge, but instead provides an opportunity for curious pedestrians to wander along the existing exterior pathway. The building's entrance and overhead door are relocated to the back of the building (Boteler Street) for discrete removal of byproducts. Materials partially match the palette used by the Cathcart Lead Facility. Oversized copper modules juxtaposed with a vertical grey wood composition present a distinctly non-residential façade. A number of aluminum baffles similar to those of the Cathcart Lead Facility are used to visually elongate the building and direct attention to its unusual proportions. The baffles control openings by selectively blocking the inner workings of the facility from the street edge while allowing perpendicular views of equipment positioned in chronological format along the straight edge of the building.

Figure 52: Bolton Street Complimentary Facility. The first four massing sketches show an early attempt at a complimentary facility without any connection to the lead. The fourth iteration, while appropriate for the purposes of wastewater treatment, does not necessarily demonstrate strategies needed to augment public risk perception. By leveraging the architectural conventions of the Cathcart Lead Facility, the building quickly resolves to a much more suitable design for the neighbourhood.

Forward Lead Facility

The Forward Ave Facility is an attempt to reconcile an urban wastewater treatment facility in the Mechanicsville neighbourhood. Mechanicsville is a traditional, blue-collar neighbourhood flanked by wealthier areas undergoing gentrification. The neighborhood profile is characterized by residential two-storey dwellings from the early 1900s complimented with infill development as well as a number of high-density social housing projects. The area is bound by a series of arterial routes that lead to the city. Mechanicsville suffers from a lack of green space compared to surrounding neighborhoods.

To adjust to the social and contextual needs of Mechanicsville, the secondary program of a decentralized facility has been modified accordingly. Communal garden plots will be developed as part of the building's landscaping efforts, with treated effluent irrigation and manure provided by the facility. In this way the benefits of the building are made aware to the community. A standing pool similar to that of the Cathcart Lead Facility creates a direct connection to the building's primary function. Exterior, one-way circulation paths lead curious residents to places of educational advertising and reflection. The building's material palette is largely concrete – a material that is well understood and established within the neighborhood. The building's geometry is bisected into two oblique angled masses that envelope the exterior program and, with the help of carefully selected openings, promote transparency by diffusing the delineation between exterior and interior. A number of small but bold architectural applications, including the fractured wall plane along the standing pool, and multi-faceted roof, suggest architectural value. Openings once again provide views to the building's equipment. Views at eye-level within the primary interior circulation corridor are shielded to the outside, focusing the occupant's interest to the workings within. The by-products of the Forward Ave Facility are concentrated to the back of the lot where transportation (to truck or manure pile) can be facilitated without unduly disturbing the secondary program. The building's chevron-style geometry creates a welcoming exterior space with intriguing openings, giving neighbors and residents an opportunity to safely and pleasantly engage with the building. Despite the materials used, the building remains sensitive to the surrounding context through relatively austere volumes and lack of ornament. A variety of imagery, including the half-gable window used along the North facade of the Cathcart building has been added to provide linkages to existing facilities.

Figure 53: Forward Ave. Facility

Breezehill Complimentary Facility

The Breezehill Complimentary Facility, along the western edge of Little Italy, demonstrates how a complimentary facility can operate within the urban-industrial neighbourhood context. The immediate area boasts a number of small commercial ventures predominantly located in large warehouse complexes, as well as a series of moderate industrial workshops, manufacturing spaces, mechanic's garages, and smaller residential housing typologies primarily occupied by the city's Italian community. Little Italy is severed by several major East-West and North-South circulation routes (Somerset, the Queensway, The O-Train, etc...) and is parceled into autonomous quadrants.

The Breezehill Complimentary Facility is more regimented than the Forward Ave facility in order to establish itself appropriately within the streetscape. The building consists of a single rectilinear volume appended to an existing garage. Materials and imagery remain consistent between Forward and Breezehill, with similar concrete and wood elements used to express the main volumes. Half-gable, oversized openings showcase much of the work that occurs within. A large vertical marquee takes advantage of monitoring equipment to display the number of treated gallons of effluent processed by the facility, visually advertising the benefits of the building. As with the Forward Facility, portions of publicly-visible façades are intentionally left flat in order to showcase educational materials. The nearby sewer drain is painted a vibrant color to connect process with the facility. Transportation of by-products is relegated towards the back of the building, with a primary entrance located near the front.

Figure 54: Breezehill Complimentary Facility.

Figure 55: First and second iterations of the John Street Facility.

John Street Complimentary Facility

The John Street facility is located in heart of the affluent New Edinburgh community. The neighborhood profile consists of large, colonial-style residential buildings bound by the Ottawa River, the Rideau River, and the 88-acre estate of Rideau Hall. The John Street neighborhood, in stark contrast to Mechanicsville, has a great deal of green space. The neighbourhood benefits from a wealthy community organization and has undergone significant gentrification over the last fifty years. Large, single family dwellings and a 'NIMBY' mentality make the neighbourhood a difficult site for the installation of a decentralized facility. The socio-economic status of the neighbourhood suggests that the New Edinburgh community should understand (and subsequently embrace) the precepts of wastewater treatment. The issue is one of aversion to a departure from the established housing typology, compounded by proximity.

For these reasons, the number of individual treatment facilities required to treat a substantial amount of the John Street CSO have been clustered into larger groups to avoid overwhelming the community with numerous iterations of a disagreeable building use. As the needs of the community are few, emphasis on the building's design and programming revolve around the idea of neighborhood preservation. Through capitalization of the building's services, the community's way of life can continue without the need for larger infrastructure projects. Opportunities to 'green' the neighborhood through tertiary wastewater treatment are also identifiable benefits to the community. By viewing treatment facilities as a means of preserving the desirable green space, cleanliness, and quietude of the neighborhood, the building itself can be seen as a positive attribute to the community. The architecture, therefore, must be especially sensitive to the immediate context.

By clustering the dozen facilities needed to treat a substantial portion of the John Street CSO into groups of three, only four sites are required within the neighborhood instead of twelve. This limits the pervasiveness and prominence of the building type. The building itself is kept to the minimum dimensions required for adequate tertiary treatment with requisite sound and vibration isolation. A notable feature of the New Edinburgh neighborhood is that shared parking often exists in the middle of the block, with low individual garages bracketing an access point from the street. This results in a series of utilitarian, one-storey buildings set 40 or 50 feet back from the front property line. The spaces created by this arrangement are often ideal for the location of a treatment facility.

A number of different iterations were sketched and developed in order to find a design appropriate for the neighbourhood. Initial sketches produced concrete and wood facility expressed in a somewhat soft and airy volume that looked like an extension to the existing nearby house, rather than a purpose-driven building. The residential extension helps visually blend the facility into its surroundings, but does so in a dishonest way that has been met with resistance in the past. To address issues of transparency, a second iteration re-introduced the unusual volumes required of a treatment facility by visually fracturing the building back down to three identifiable masses, while still retaining elements of the urban fabric. This helps break the residential association, but also creats an undesireable disconnect with the adjacent buildings. Materials in the second iteration include stone and steel in an effort to demonstrate durability. Openings in the existing brick wall were created to facilitate views inward from the street, and were later staggered against openings in the building's envelope to create selective sightlines. As with Bolton, views into the treatment facility are shielded from the street and sidewalk, but easily accessible simply by standing in the right place, allowing curious residents to see the inner workings of the facility.

In the building's final iteration, the building's three masses are once again delineated, this time primarily through a complex roof plane that cuts into the building at right angles. The gable roof of the garage to the North picks up the roofline of the facility, integrating the building into the existing utilitarian buildings in the center of the block by blending visual datums. The primary massing facing the street edge is once again employing wood to provide a softer, more welcoming public façade, but takes advantage of a slatwall paneling system that is more commonly associated with larger commercial and office typologies. The front façade is carved into larger repetitive modules through the introduction of thin vertical channels, with openings placed in every second bay providing views to filters, aeration tanks, holding chambers, and blowers. Brick has replaced steel paneling in order to better compliment the older masonry homes in the area, with oversized bricks used to artificially age the building.

The utilitarian buildings grouped around the center of the John Street block prevent by-product pick-up from occurring at the rear of the building, requiring an overhead door that faces the street. In lieu of a depressed driveway or commercial overhead opening, the interior floor is raised 30" to accommodate the bed of a light-duty truck, and recessed behind the envelope allowing a more conventional overhead door to be placed at grade. A small brick expanse is extended past the garage door to elongate the front elevation, preventing the door from becoming a visual anchor.

1: CENTRAL TRANSPORTATION BY NECESSITY
2: PRIMARY MASSING BAY
3: BRICK CONTOUR AROUND SECONDARY VOLUMES
4: CONTINUATION OF BUILDING FORM FROM ADJACENT UTILITY BUILDINGS
5: SELECTIVE OPENINGS IN BRICK WALL AND PUBLIC FACADE
6: WATER FEATURE
7: CONTINUATION OF BRICK + EDUCATIONAL ADVERT.
8: HARD LANDSCAPING

Figure 56: Third iteration of John Street Facility.

Summary

A categorical analysis of facility designs within different urban neighbourhoods has identified a number of shared commonalities that appear to exist independent of context:

- **Unusual Volume:** Complimentary facilities occupy a footprint of approximately 50' x 8-12', an unusually long and narrow volume to contend with in urban spaces. These volumes often take advantage of the long axes of urban plots while leaving space along the "short" side, constraining exterior circulation, site programming and landscaping. In some cases, multiple MBR systems can be re-arranged in modular forms to take advantage of compact sites, or gentrified neighbourhoods with 'NIMBY' attitudes.
- **Material and Module:** Materials need to express durability, longevity, and value, which, in many cases, lead to stone, metal and composite materials often found in civic, institutional and tower typologies. These typologies typically employ 4'+ modules, which are often too large for an urban facility volume. Employing these materials using residential modules of 4" – 12" was also avoided in many cases to prevent undue repetition along the long axis of the building, as well as to avert residential association. One common convention is the use of modules in the 2'-4' range, which is somewhat unusual for the building with such a narrow footprint. This module can often stagger visual breaks in the building in an unconventional manner.
- **Openings:** The windows in these facilities are designed to look in, rather than out. The equipment inside a treatment facility can be quite visually appealing at all heights, suggesting that openings at all heights are useful in promoting transparency. Legibility requires the thoughtful curation of these openings, so the commercial storefront full-height glass wall is not advocated. The goal of the openings is to selectively showcase and inform, and not overwhelm. In this way glazing is neither residential, nor commercial.
- **Entry:** A predominant sense of entry is not needed in complimentary facilities. Service entries at the rear of the facility (adjacent an overhead door) are often a much better approach for the prescribed program. The removal of a front door effectively limits an association with the residential typology.
- **Primary Long Axis:** Equipment should be set in a linear, chronological fashion that coincides with a linear circulation path. In most cases this will be stripped down to a simple circulation route along the primary axis.
- **Comprehensive Material Palette:** Lead facilities with secondary programs are generally big enough in scale to warrant 3 materials. Complimentary facilities should take advantage the lead facility material palette to emphasize their relationship. This is often an unusually large palette for a building this size and requires careful architectural intervention.
- **Connection to Process:** A connection to process is required. Highlighting or otherwise revealing infrastructure can promote awareness of the building's function. This can be done with use of glass, landscaping, color coding, or by visually denoting sidewalk drains, gutter, or water leaders. Prominent positioning of water-related elements can be helpful, suggesting careful positioning of mechanical systems that transport water.
- **Water Feature:** Connection to process is also helped by visually demarcating cleaned water coming out from the building. Water features such as pools, fountains, exposed discharge methods, holding tanks, or even drinking fountains are encouraged as a means of understanding the building's function.
- **Disconnect from Industrial Typology:** Industrial characteristics are unnecessary – lead and complimentary facilities do not need to employ typological characteristics identified in Appendix A. Industrial characteristics can be perceived as out of place in certain neighborhoods, and can heighten risk-perception.
- **Landscaping:** Hard landscaping is often required to accommodate exterior pedestrian routes and water features.
- **Rear Transport:** Transportation is better suited towards the rear of the building.
- **Disconnect from Repetitive Imagery:** Consistent imagery is unnecessary. Imagery is often used to help form a typology (church steeples, for example), but is not necessary in a responsive building that adapts programmatically to its context. The half-gable windows used at Forward and Bolton weaken the building's overall position, rather than strengthen associations to the building at Cathcart.
- **Educational Advertising:** Flat expanses at the public edge are helpful in creating a space for large printed educational material. Empty space near the public edge of the building is also useful for water pumps or marquees.
- **Transition in Articulation:** While not necessarily an architectural characteristic, a noted, repetitive design element depicts one side of the building as being heavily articulated and organic, with the opposing side rigid, static, and rectilinear. This may be the result of having a long tank against one side of the building, and smaller components and circulation space on the other. In a similar fashion, many top loaded MBR systems require additional headroom, creating two distinct volumes – one with a head height anywhere from 14-18', and the second anywhere from 8'-12'. Forward Lead Facility is an example of this functional constraint.

Discussion

Type and Typology

The concept of type and typology in architecture has been rationalized over the last few centuries through several philosophies. Enlightenment philosophy, accredited to the work of Quatremière de Quincy (1755-1849) discusses the concept of the model (the mechanical reproduction of an object) and the type (a metaphorical entity). Type in this sense expresses "permanence, in the single and unique object, of features which connect it with the past."[194] Quincy's features are based on the charactere recognized by Germain Boffrand (1667-1754), defined as the "expressive function of a building [used] to communicate with people."[195]

In 1801, J.N.L. Durand (1760-1834) published Recueil et parallele des edifices de tout genre, a major work that broached the classification of architecture through form and geometry, and furthered the concept of type from the intangible idea to the irreducible (but tangible) element. By introducing fundamental precepts such as precedent, taxonomy, and continuity, Durand's ambitious work aimed to systematize architectural knowledge.[196]

Modernist and Neo-Rationalist perspectives carried this notion idea of type into the 20th and 21st century in an attempt to rationalize the theoretical development of typological study. Type today can generally be defined as as "a concept which describes a group of object characterized by the same formal structure, and is fundamentally based on the possibility of grouping objects by certain inherent structural similarities,"[197] where the "formal structure" is a very broad term encompassing everything from social activity to building construction to abstract geometry. Typology in its strictest sense refers to the comparative study of distinct type; of the "physical or other characteristics of the built environment."[198]

Using a modern definition, the formal structure presented in many of the designs in the D9B module have a several common characteristics that create a distinct formal structure and unique consistency. Specific geometries, volumes, construction and social relationships distinctly frame an architectural group flexible enough to adapt to unique contexts (i.e. 'susceptible to differentiation in their secondary aspects'[199]). Furthermore, as the idea of type is self-determinant, it is suggested these facilities would define their own type through their precise position in time and history. Urban treatment facilities would create a new set of formal relations within the city due to lack of precedent (the theoretical model), facilitating the generalized mechanisms required for a new type. From this one may conclude that the design experiments conducted within the D9B module suggest potential for the development of a new typology, but further rationalization would require the self-realization (and actual construction and establishment of the reproducible model) of these facilities.

Subjectivity

Design is a subjective process, and different designers will derive different solutions in response to a specific design problem. The urban treatment facilities presented in both the D9A and D9B module are by no means absolute or exhaustive solutions to their respective design criteria. The value of this research is predominantly high-level and categorical, and attempts to develop and understand the characteristics that create the 'formal structure' of type. Knowing what questions to ask, and understanding the process required to develop an architecturally sensitive treatment facility is of great value within the design paradigm.

The application of identified characteristics to existing treatment facilities has, in the author's opinion, resulted in an improvement to the architecture through the establishment of type. A countering opinion would be that these improvements are attributed to a greater investment of time into the design. This argument can in turn be contested with the concept that invested time refines a project in any given direction, but an investment in guiding principles constrains the direction of the design. The abstract refinement of a treatment facility can polish a design without resolving it, as shown in early iterations of the Bolton and John Street facilities (Figures 17 and 20). Investment into typology may require a designer to abandon an existing proposal regardless of its state of completion, and start fresh, as seen in the later iterations of both Bolton and John Street.

Application

A great deal of the research behind the project is applicable to the architectural design and implementation of infrastructure and other civil engineering projects, as well as building functions publicly perceived as risky. Examples of similar applications in the D9A module include cell phone towers, electrical sub-stations and subway ventilators. Other potential applications include public washrooms, wind turbines, hydro dams and other generators, regulators, waste-to-energy facilities, trash harvesting facilities, snow dumps and snow disposal facilities, and even temporary housing for construction projects. The underlying strategies and their interpretation within the built form (prior to the addition of context) provide an understanding of how architecture can positively contribute towards risk-management. The exploration of process through multiple iterations can be tailored to external objectives, with any resulting characteristics applied in a similar fashion to provide visual guidance for positive design.

It is also important to understand where decentralized facilities will not be a viable alternative to grey and green infrastructure solutions. In urban areas where wet weather events and sewer grid patterns result in infrequent, high volumes of combined sewage in short durations, decentralized facilities are unlikely to be much more effective than the alternatives. In other instances, high numbers of individual treatment facilities may be required to substantially solve the problem. Furthermore, in areas with limited urban space (due to close proximity between primary sewers and surface water, geographic constraints, economical issues caused by land premiums, or a combination of all three factors), the amount of facilities that can be feasibly constructed may be not capable of mitigating the CSO in question to any substantial degree.

Conclusion

Current strategies for mitigating combined sewer overflows can be impractical, unfeasible, and cost and scale-prohibitive in urban areas. Decentralized, small-scale wastewater treatment should be considered as a potential solution in areas that require source-sited treatment. At an urban scale, and within the context of a larger centralized system, these satellite systems can help mitigate combined sewer overflows by treating sewage at the source of the problem.

In order to bring wastewater treatment into urban areas, issues of scale, noise, smell and discharge method must be addressed through modern engineering practices and technology. Packaged plants in conjuction with odour control equipment, noise mitigation methods, and strategies for effluent discharge and by-product removal can overcome the physical barriers that have prevented wastewater treatment from being sited in urban areas in the past.

The remaining obstacle to urban wastewater treatment is a psychological aversion to waste treatment. Research has shown that a number of strategies can help overcome this aversion, including trust, transparency and legibility, positive form association, education and awareness. These strategies can translate into architectural elements and characteristics that can help mitigate public aversion and opposition to wastewater treatment. Precedent research shows that successful conventional wastewater treatment facilities are developing an architectural language that employs these strategies.

Through the application of the functional and programmatic elements required for decentralized wastewater treatment, prototypes can demonstrate proof of concept for the successful integration of wastewater treatment within urban areas and at urban scales.

Contextualization of the decentralized facility prototype has shown that the decentralized model can be constrained by the nature of a city's wet weather events, as well as by existing sewer infrastructure. Cities and municipalities that experience sudden, severe, and infrequent wet weather events may not be suitable candidates for decentralized facilities. Furthermore, as the effectiveness of a facility decreases with each successive iteration at a particular CSO site, full remediation of combined sewer overflows may not be seen as an economically viable strategy. Understanding the relationship between a facility's effectiveness and the behavior of a specific CSO can help determine how many decentralized facilities are required to mitigate a substantial amount of the problem. This number in turn directly informs the feasibility of establishing facilities within a particular neighborhood.

It has been sufficiently demonstrated that disguising unpleasant buildings, functions, and infrastructure is not a satisfactory design response to an urban problem. In the case of urban wastewater treatment, it is important to address public risk perception by architecturally interpreting risk-mitigation strategies, while simultaneously respecting and responding to the building's urban context. As shown through a series of design tests in varying urban spaces and neighbourhoods, a wide variety of common architectural elements do persist between facilities independent of their site. Benchmarking the value of these commonalities is difficult given the subjective nature of design, but it is strongly suggested that buildings that ignore the unique characteristics inherent in the urban treatment facility type cannot be successfully established in urban communities. It is instead suggested that the incorporation of identified characteristics developed in this paper can positively influence decision-making within the design process, and ultimately, and successfully, resolve a decentralized wastewater treatment facility within urban neighborhoods.

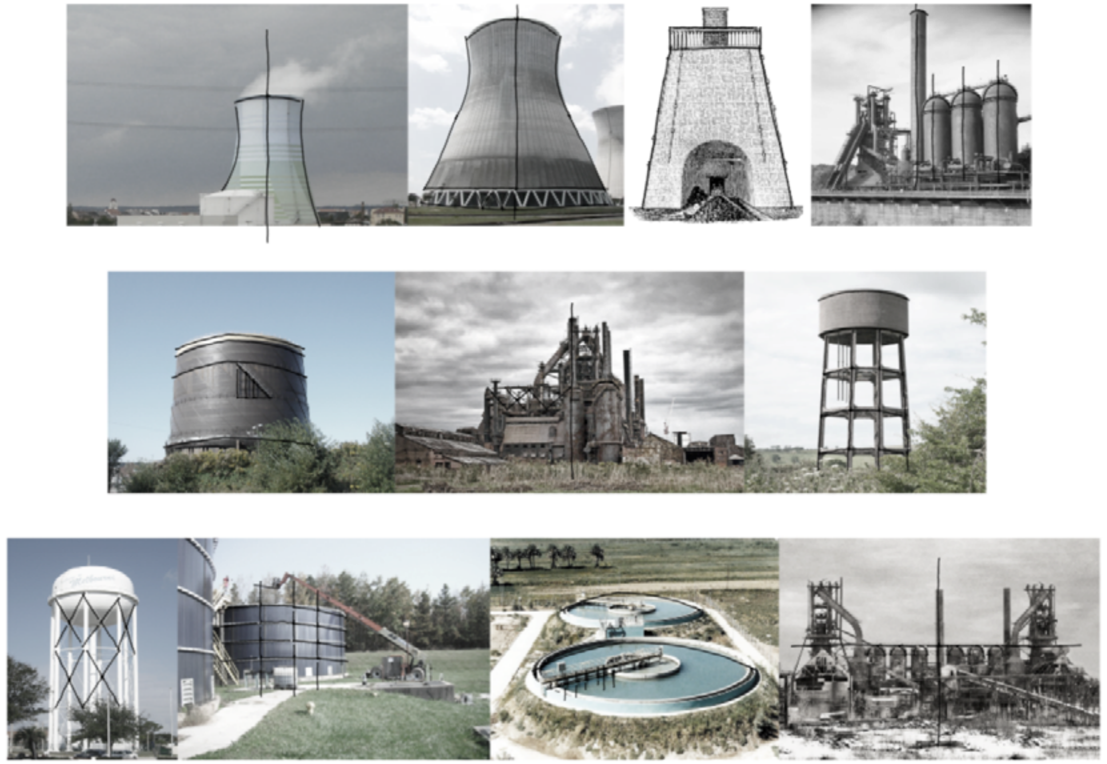


Figure 57: Commonalities in cooling towers, gas boilers, mills, settlers and water towers.

Appendix A: Characteristics of the Industrial Typology

Conventional wastewater treatment facilities are predominantly associated with industrial characteristics, pattern and scales. These elements are historically consistent with rural development intensity. Industrial architecture is extremely functional. Common forms derived from industrial applications are based on the requirements for tanks, towers and boilers. These forms have historical significance in collective memory.

Because the function of industrial buildings generally involves the movement, storage or processing of raw elements, the corresponding forms and themes must facilitate these actions. Elliptical and circular forms are characteristic of the industrial typology. Tapering of the top or the base allows for the expansion or consolidation of raw materials. Secondary ‘hatched’ forms representing scaffolding, circulation, structure, or mechanical conveyance provides an outer ‘wrapping’ that allows people to service and make use of these massive structures. These secondary forms often follow a grid that can run parallel to the primary visual lines, or run diagonal to the composition. Strong symmetry is often the result of balanced systems and processes.

Specific to wastewater treatment facilities are settling tanks, clarifiers, contactors and basins. Primary settling occurs in round or rectilinear concrete tanks that are often partially buried and open to the air. Mechanical rakes or weirs rotate around the tanks to remove solids and add to the cyclical imagery associated with treatment facilities and water systems in general.

Secondary treatment can occur in settling basins, in large rectilinear tanks, in contactors (which allow influent to filter through media), or in lagoons. In most cases a cyclical or rotational element lends distinction to the primary form. Secondary units used for auxiliary purposes (heat generation through biogas produced by bacteria, sludge processing for manure, etc…) are housed in purpose-built utility buildings.

The scale of these forms is not pedestrian friendly, causing industrial buildings to seem overwhelming due to their size. Material choice often responds directly to issues of durability, resulting in large steel panels, pre-cast and poured concrete slabs and tanks that contribute to an overall monolithic impression. Pattern is seamless, perfunctory, and rarely breaks up the scale of the building. The hatched, grid-like secondary elements often serve to augment the immensity of the primary mass, rather than break it down.

The wastewater treatment processes that occur within these forms are not pleasing. Aeration processes inherent to wastewater treatment requires large bubbling tanks of sewage. It is important to note that it is the raw material that is distasteful – the form of the tanks and the idea of aeration are both acceptable practices in themselves.

The industrial program, being a functional one, often does not provide much opportunity for public engagement. Spaces are purpose-built for very specific, repetitive actions, and are prescriptive in that they regulate the behaviour that occurs within them. Site selection is typically rural and located away from residential areas if at all possible. In some cases, natural filtration processes such as lagoons and constructed wetlands provide some opportunities for wastewater treatment to blend in with the environment, which can make their primary functions difficult to detect.

For these reasons, the industrial typology does not facilitate any kind of meaningful public experience, and often lacks context outside of its own immediate site. It does, however, present opportunities to identify and develop elements of trust and transparency, and positive forms that can be adopted at the urban scale.

Figure 58: From top left to bottom right: activated sludge basin, rotating biological contactor, lagoon, settling tank. Images courtesy of Biostrainz.com, Rotatingbiologicalcontactor.com, Rockymtnhouse.com, Tankonyvtar.hu.

Appendix B: Re-Development

The preceding list of characteristics developed through preliminary design exercises can be validated within the design parameters discussed in the *Subjectivity* section of the Discussion through the re-application of the characteristics derived from facility tests. A visual examination of how this re-application improves the building design can help determine if identified characteristics are able to successfully reinforce architectural strategies that augment public risk perception.

In the case of the Forward Ave. Facility, the material palette has changed to incorporate larger concrete modules. Imagery has been removed. Openings have been appropriately re-sized to focus on specific equipment, creating unusual visual breaks in the façade. Connection to process has been further delineated through educational advertising towards the back of the building along the treated effluent pool. A larger concrete module has been introduced.

The Breezehill facility has been modified to incorporate the same palette as Forward. The entrance has been relocated towards the back of the building, and windows have been repositioned to provide visual interest at unusual datums. A connection to process has been further delineated by prominently linking the adjacent storm drain, as well as by providing a farm pump complimented with visual advertising demonstrating the number of gallons of effluent treated by the building.

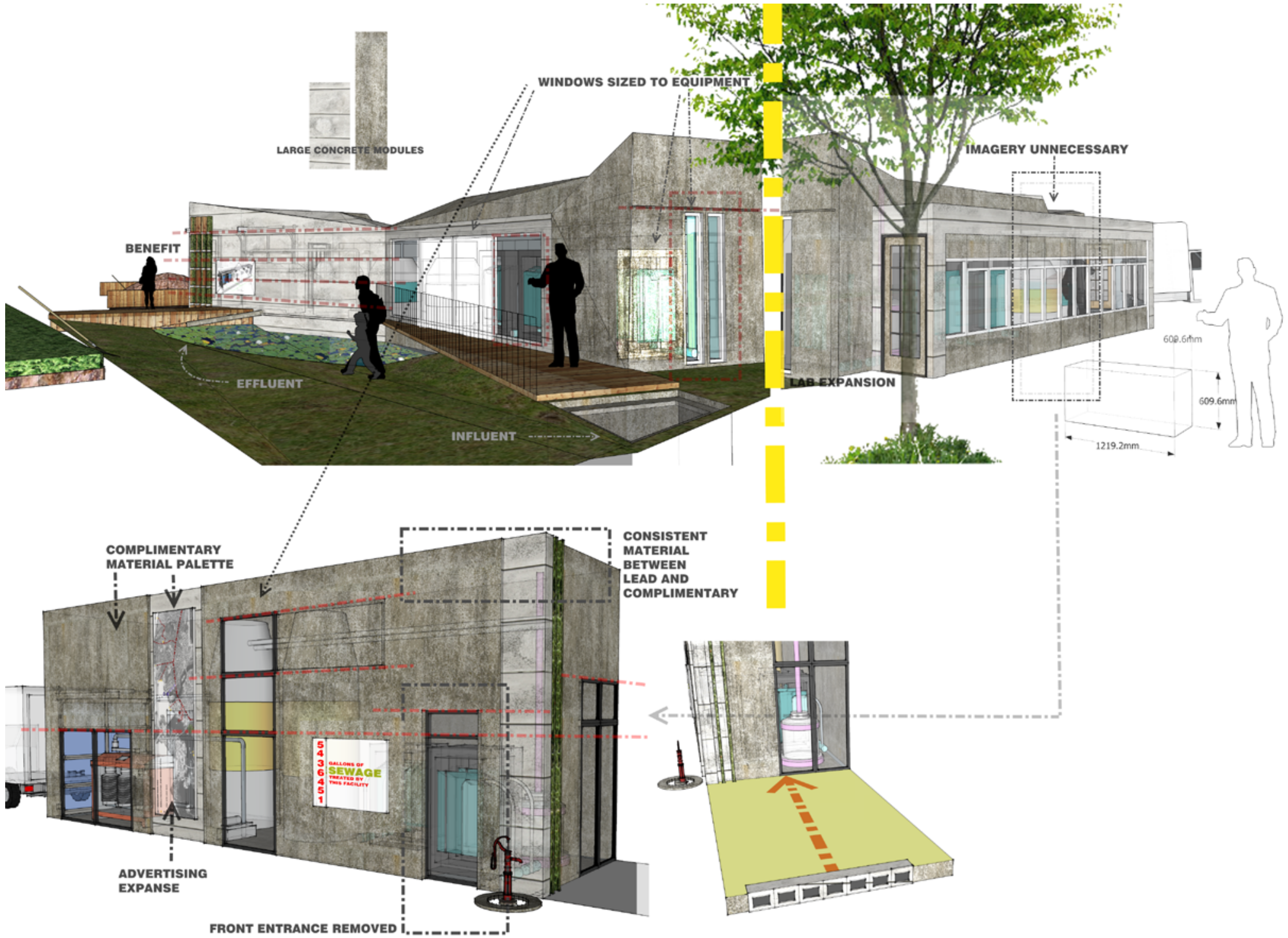


Figure 59: Forward and Breezehill Facility Re-Development using characteristics derived from earlier facility tests.

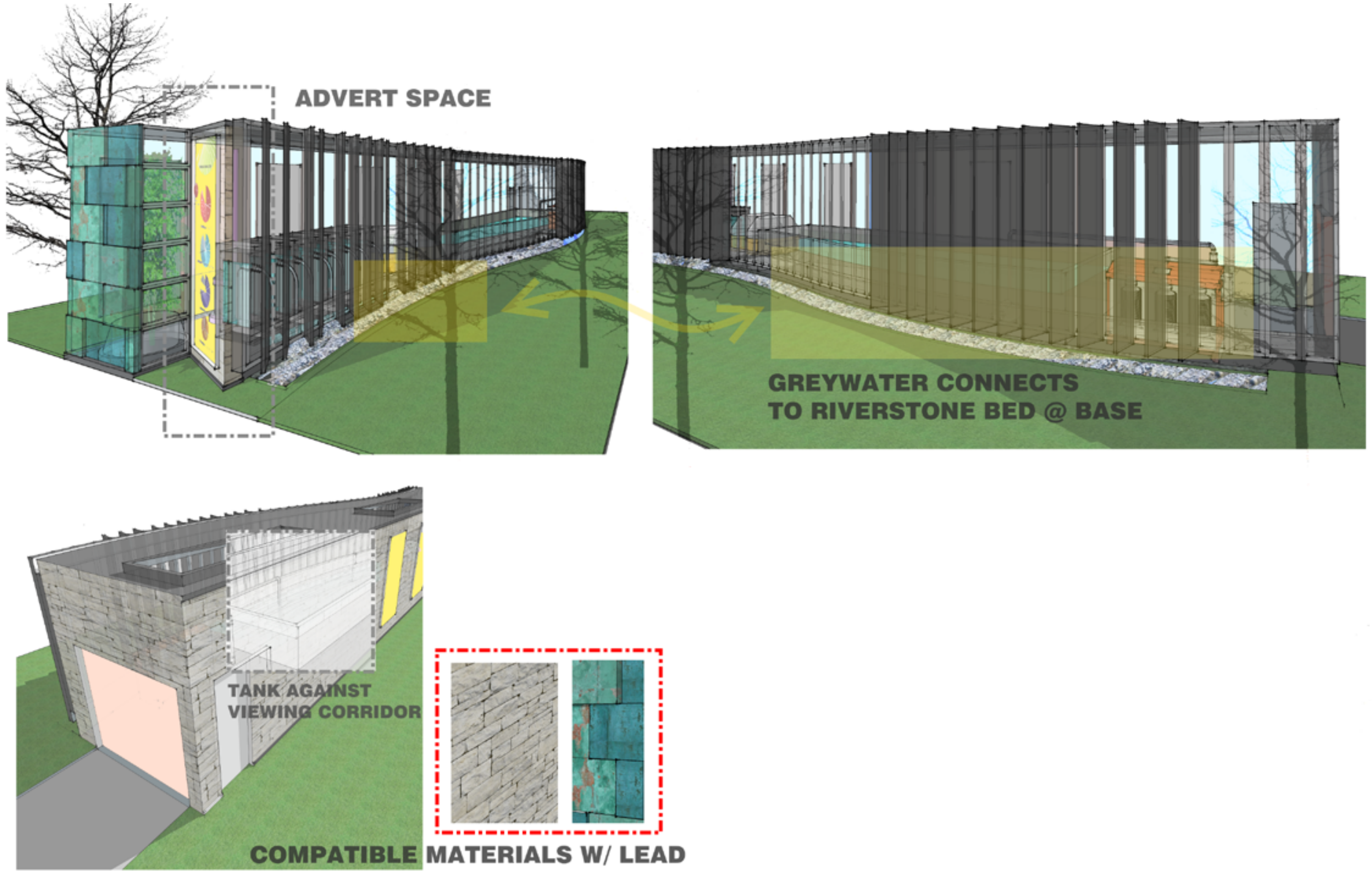


Figure 60: Bolton Street Re-Development.

The Bolton Street Facility already subscribes to many identified characteristics in the summary list. Updates to the facility include replacement of the wood façade with the ashlar stone pattern used at the Cathcart Street Lead facility. The space also now doubles as an expanse for educational advertising. A riverstone bed is added at to the bottom of the curved wall, and a small amount of treated effluent is pumped out over this medium to create a stronger connection to process.

The original iteration of the John Street Facility was improved through larger window modules that captured better views of interior processes. The front entrance was relocated to the back of the building. The softer wood façade was replaced with stone to disassociate the facility from the adjacent house. The height of the brick wall was adjusted to provide better views to infrastructure from the sidewalk. Major sewer infrastructure entering and exiting the building was exposed directly outside the building, in a detail similar to that used at the Cathcart facility.

In the final iteration of the John Street Facility, major transitions included an attempt to open up adjacent landscaping to provide truck access off the side of the building, rather than off the front. The slatwood volume is extended out, with spaces for educational advertising where the original overhead door was located. As this increases the perceived size of the front façade, the rectilinear bays have undergone an organic transformation to soften its rhythm without changing the position of openings. The organic edge further delineates the facility from both residential and industrial typologies, creating a more pleasing volume.

Figure 61: John Street Re-Development.

Glossary

Adsorption: A mass transfer process which involves the accumulation of substances at the interface of two phases, such as, liquid-liquid, gas-liquid, gas-solid, or liquid-solid interface. The substance being adsorbed is the *adsorbate* and the adsorbing material is termed the *adsorbent*. The properties of adsorbates and adsorbents are quite specific and depend upon their constituents. The constituents of adsorbents are mainly responsible for the removal of any particular pollutants from wastewater.[21]

Aerobic: Bacteria that produce energy from organic matter in an oxygenated environment.

Anerobic: Bacteria capable of producing energy from organic matter without the presence of oxygen.

Biosolids: Organic matter recycled from sewage, especially for use in agriculture.

BOD_5: Biochemical Oxygen Demand: The amount of dissolved oxygen needed by aerobic organisms to break down organic material.

Brominated Flame Retardants: Synthetic compounds that have an inhibitory effect on the ignition of combustible organic materials.

Color Disc Colorimetry: A test that measures the absorbance of particular wavelengths of light by a specific solution.

Contact Stabilization: A wastewater treatment process often used in systems with limited detention time.

Dentrification: A process of nitrate reduction performed by anerobic bacteria.

Drop Count Titration: Test used to determine chlorine, suflite, nitrogen and dissolved oxygen content. Performed by adding titrant to a sample until a color change is induced.

Extended Aeration: A treatment process often used for industrial wastewater.

GPD: Gallons per day.

GPM: Gallons per minutes.

Hopper: A large, pyramidal shaped container used in industrial processes to hold particulate matter.

Methanogenesis: The formation of methane by microbes known as methanogens.

MGD: Million gallons per day

Nanofiltration: A form of microfiltration

Nitrification: A process by which ammonia is converted to nitrates by bacteria.

Scum: A layer of dirt on the surface of a liquid.

Sequence Batch Reactor: Industrial processing tanks for the treatment of wastewater.

Sludge: A heavy viscous mixture of liquid and solid components.

Trash Rack: A large wooden or metal structure that prevents water-borne debris from entering an intake.

Weir: A barrier used to alter the flow characteristics of water, often used to remove obstructions.

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Water Hospitals
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