The world's largest rain barrel

Chicago considers repurposing an abandoned tunnel into a massive rooftop rainwater collection system

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Limited access to resources and the increasing complexity of mobilization and construction in urban areas can deter utilities from capital improvement projects. One alternative to overcome these limitations is infrastructure and capital partnerships among municipal agencies. These partnerships provide a platform for highly creative, cost-efficient, and sustainable solutions by introducing the potential for significant cost-saving and cost-sharing opportunities. The opportunity for one such project partnership arose between two agencies in Chicago. They currently are exploring an innovative approach to stormwater management by repurposing an abandoned water tunnel for stormwater storage.

The Chicago Department of Water Management (CDWM) recently abandoned a potable water tunnel constructed in 1907. In the past, abandoned water tunnels in Chicago have been bulkheaded, rendering these infrastructure investments virtually useless. Instead of allowing this tunnel to remain abandoned, the Metropolitan Water Reclamation District (MWRD) of Greater Chicago and CDWM are partnering to explore the potential to repurpose this century-old water-conveyance tunnel as a stormwater-capture tunnel, harvesting rainwater from rooftops with significant surface area in the surrounding urban subcatchment – essentially creating the world's largest rain barrel.

The need to address stormwater

MWRD has been a prominent flood-control leader in Chicago since the 1960s and is the current stormwater management authority for Cook County. Increasing urbanization of Chicago and the surrounding suburbs, coupled with increasing severe storm frequency, has raised concerns for localized flooding.

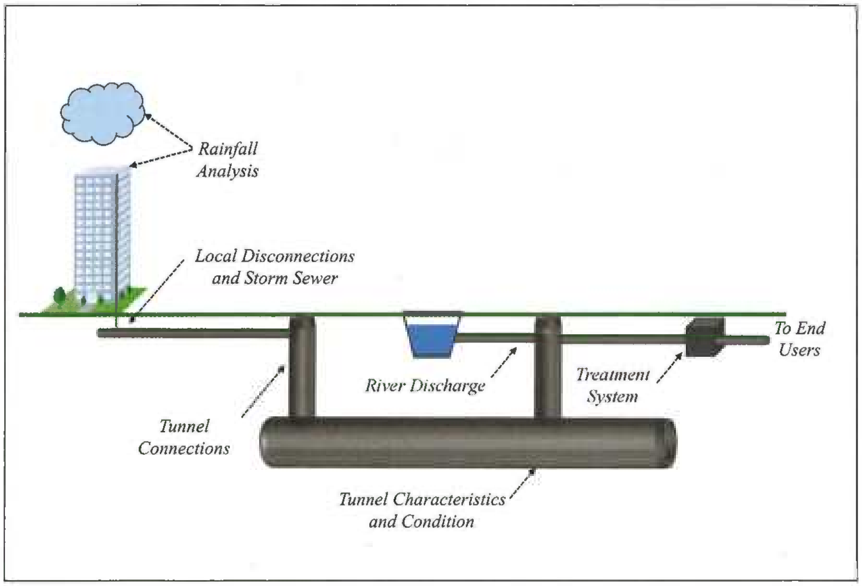
In early 2014, MWRD entered into a consent decree with the U.S. District Court stipulating terms for the long-term control plan. One section of the document specifies a requirement to implement green infrastructure controls. MWRD and Greeley and Hansen (Chicago) collaborated to identify innovative green-infrastructure projects to meet the consent decree and reduce flooding and stormwater damage.

In late 2013, roadway improvements in Chicago required that CDWM abandon use of its Blue Island Avenue potable water tunnel. The 2.4-m- (8-ft-) diameter tunnel, in operation for more than 100 years, conveyed potable water between two pump stations. The abandoned portion of the water tunnel spans more than 4.8 km (3 mi; see Figure 1, below), with a potential storage volume of up to 22,712 m^3 (6 million gal).

Figure 1. Abandoned portion of the Blue Island Avenue Tunnel

Map data ©2015 Google

Figure 2. Areas of focus for feasibility study



Tunnel characteristics and condition

The Blue Island Avenue Tunnel follows street lines, traversing approximately 8077 m (26,500 ft) at a depth of 10 to 23 m (34 to 74 ft). As the tunnel passes below the river, it drops to 74 ft. The cross-section was constructed as a circular, uniform 2.4-m (8-ft) diameter tunnel, lined with 25 cm (10 in.) of concrete. (See Figure 3, below.) As with most of Chicago's original water tunnels, the Blue Island Avenue Tunnel was installed primarily in clay layers, except for a few short stretches where the tunnel was bored through sandy soil or soft clay. Where the tunnel passes under the Chicago River, the lining is reinforced with longitudinal steel bars. Permeability of clay is negligible, and the clay provided firm outer support for the concrete. Minimal infiltration is expected.

Project feasibility

Before committing to a detailed project design, the agencies are evaluating the feasibility of using the potable-water tunnel as a stormwater capture-and-conveyance line. A preliminary study evaluated several key areas of focus:

- tunnel characteristics and condition,
- tunnel connections,
- local disconnections and storm sewer networks,
- rainfall analysis, and
- reuse of harvested rainwater and stormwater conveyance.

These key considerations for the stormwater tunnel overview are represented visually in Figure 2 (above).

Tunnel connections

Using the abandoned tunnel as a stormwater capture-and-conveyance tunnel requires harvesting rainwater from building rooftops and conveying that flow to the tunnel. The Blue Island Avenue tunnel was driven simultaneously from six shafts, two of which were permanent. The other four were filled and abandoned after construction.

Three shafts (shown in Figure 1) were found in the contract documents along the abandoned portion of the tunnel: Gate Shaft No. 2, Shaft No. 3, and Shaft No. 4. Based on various coordination complexities, Gate Shaft No. 2 was not advised to be repurposed. But while repurposing Shaft No. 3 was not

Figure 3. Cross-section of Blue Island Avenue Tunnel, during and after initial construction

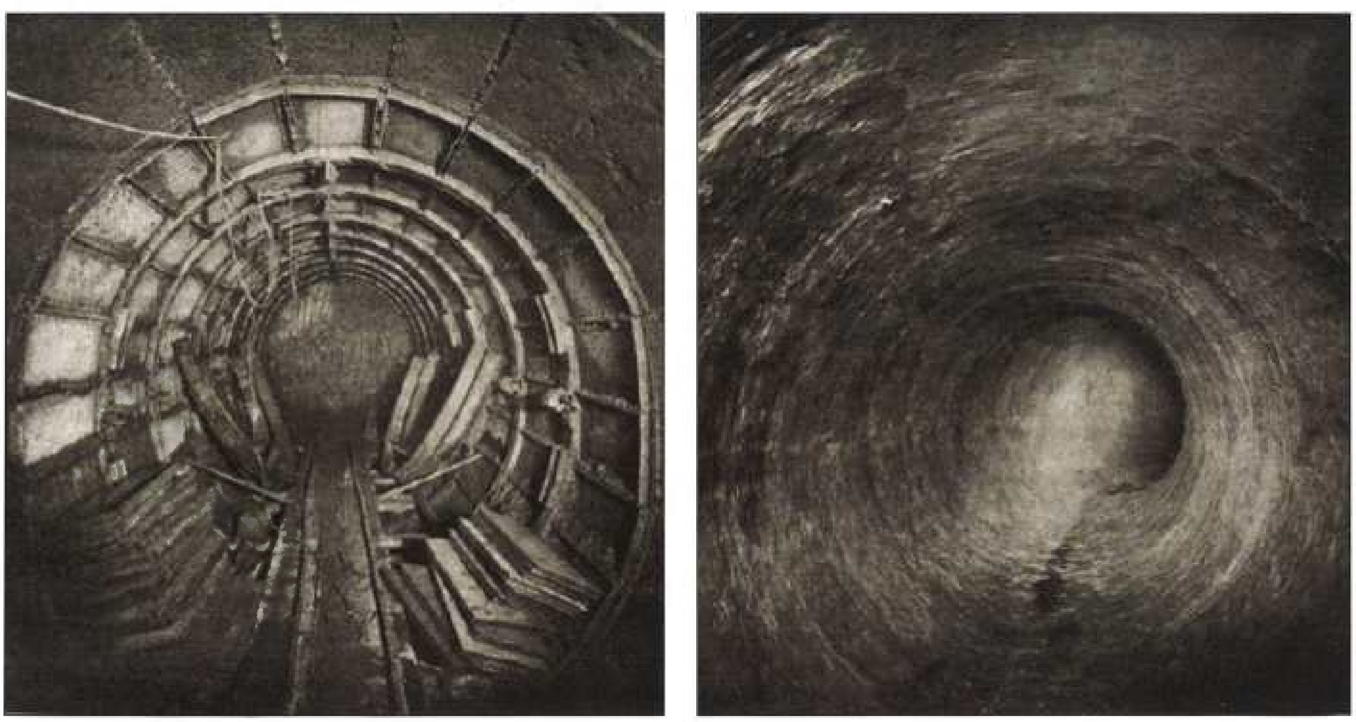


Figure 4. Identified rooftop areas and connection points

Map data ©2015 Google

recommended (as it currently houses a utility connection), the shaft's close proximity to the river would be advantageous for pumping excess water to the river.

Repurposing Shaft No. 4 was seen as a cost-effective way to add a second connection to the stormwater tunnel. Any new connections would have greater cost and uncertainty because of the material to be drilled through, coordination of utilities, and other unknowns in the field. The recorded history of Shaft No. 4 meant less risk associated with excavation material and utility interferences.

Local disconnections and storm sewer networks

Capturing rooftop rainwater for stormwater control was ideal for three reasons:

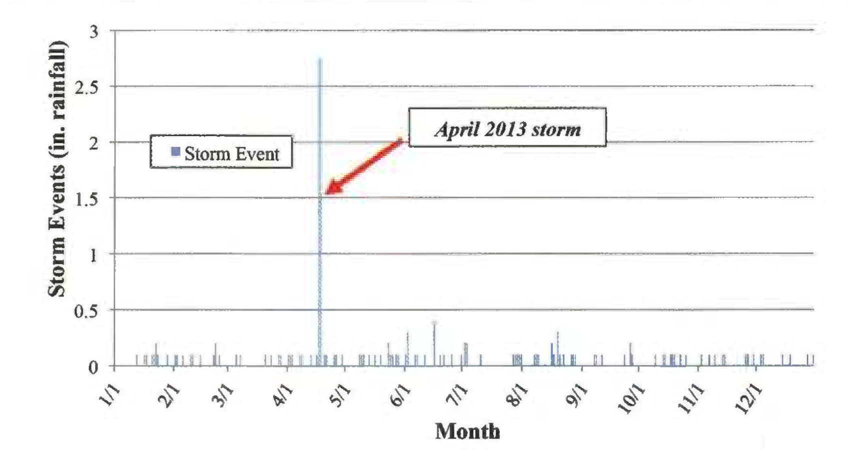
- Road inlets are susceptible to conveying solids and other materials that may require more intensive solids handling.
- Water collected from street inlets has a higher potential of containing contaminants and chemicals from road runoff.
- Many street inlets would have to be disconnected, increasing the construction cost. The area surrounding the tunnel includes residences, large buildings, and high rises, which have a limited number of stormwater inlets to the combined sewer system.

The initial downspout-disconnection effort focused on parts of the city that had buildings with significant rooftop area. Key to maximizing stormwater capture and minimizing implementation cost was identifying large rooftops near existing tunnel connection points. A new shaft near Shaft No. 3 was proposed that would allow pumping from the tunnel to the river. This shaft could also provide a stormwater input to the tunnel.

Figure 5. Rooftops near Shaft No. 3

Map data ©2015 Google

Figure 6. Typical rainfall year (with one outlier)



*This storm dropped approximately 5.5 in. of rain in 2 days.

A second area inspected for large rooftops was in the vicinity of existing Shaft No. 4. Although creating a new connection point had associated costs, reusing this area would provide benefits and potential savings.

After identifying large-rooftop buildings in close proximity to the exising shafts, new connection points were identified. (See Figure 4, p. 33.) A three-dimensional view of highlighted rooftops near Shaft No. 3 is shown in Figure 5 (p. 33).

Rooftop areas are summarized in Table 1 (below). The tiers represent phases in which the project can be conducted. Tier 1 rooftops are those close to Shaft No. 3 and have the most efficient cost–benefit ratio. Tier 2 rooftops are close to Shaft No. 4. Tier 3 rooftops all have a similar cost–benefit associated with their service area and are listed in order of total rooftop area.

It is important to note that the rooftop areas in Table 1 are estimates and that the project is not limited to only these rooftops. More rooftops could be connected to the tunnel other than those with areas greater than 743 m^2 (8000 ft^2). All local stormwater pipes could be installed to account for potential future connections.

Rainfall analysis

A rainfall analysis was conducted to assist in quantifying the benefits of disconnecting the identified rooftops from the combined sewer network. The rainfall analysis used 20 years of National Oceanic and Atmospheric Administration rain gage data from Midway Airport. Rainfall collected between 1993 and 2013 was categorized by year and month. The most typical month was selected based on the average rainfall, and the typical months together generated a typical rainfall year. The total rainfall depth generated in the typical year was 91 cm (36 in.).

Figure 6 (above) delineates the typical year by rainfall event. It is important to note that the typical year had no single rainfall event larger than the 2-year period rainfall. An outlier was added to test the performance of the stormwater tunnel under atypical storm events. The typical year and outlier event were applied to the identified rooftop areas, and the results are presented in Figure 7 (p. 35).

The following assumptions were made:

- No losses in rainwater volume occur from the rooftop to the tunnel.
- The tunnel is completely empty at the start of the year.
- The total tunnel volume is 22,700 m^3 (6 million gal).
- Operations staff chooses to pump to the river when the tunnel reaches 18,930 m^3 (5 million gal).
- Operations staff chooses to maintain 3785 m^3 (1 million gal) of storage at all times in the tunnel to maintain a reserve for water-reuse demands, except when a major storm is forecast.

Under these assumptions, the tunnel is projected to fill and pump out to the river nine times in a typical year. The total capture volume in the typical year is approximately 123,026 m^3 (32.5 million gal), with an additional 18,930 m^3 (5 million gal) associated with the outlier event in April. A summary of the capture volumes for each rooftop disconnection tier is provided in Table 2 (p. 35).

Figure 7 does not intend to emulate real operation but rather serves as a visual demonstration of the capture ability of the tunnel. Reuse of harvested stormwater will add a level of complexity to the operation. A demand curve would need to be laid over the graph and its effect factored into the tunnel real-time volume. Also, the operational assumptions of 1 and 5 million gal were preliminary and may be subject to operational preferences in future discussions with MWRD.

Reuse of harvested rainwater and stormwater conveyance

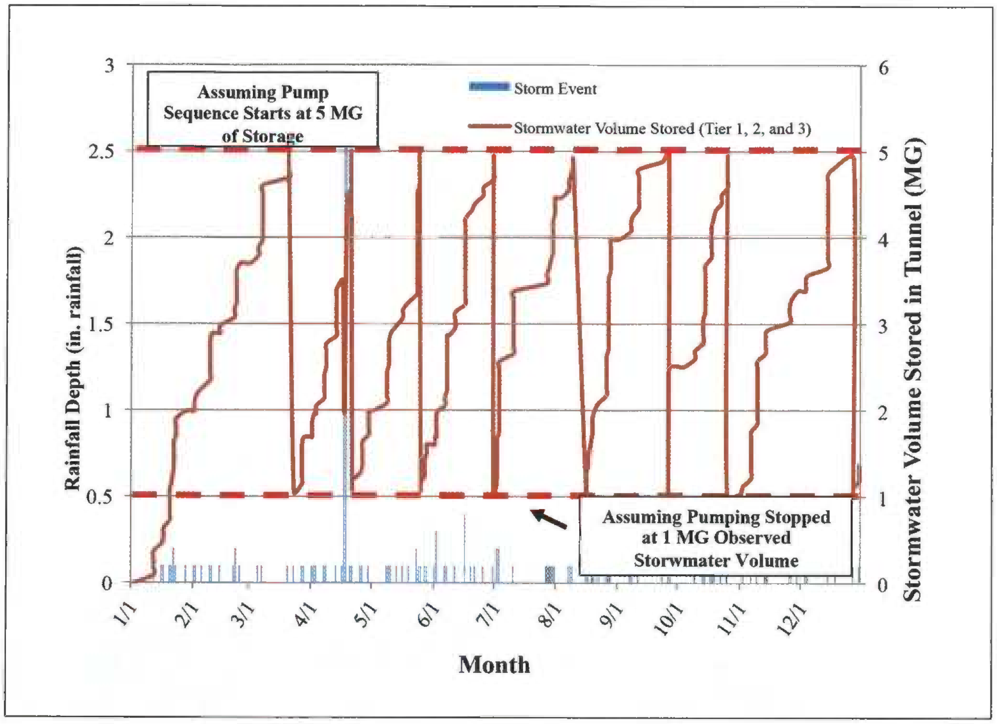
A difficult challenge for urban areas is distributing stormwater to pervious areas for natural infiltration. The new stormwater tunnel would create an opportunity to redistribute stormwater from largely impervious areas to either a nonpotable user or a green area. Distributing small pump stations along the tunnel or implementing a nonpotable loop can help accomplish this.

Currently, no standard water-reuse regulations exist for Chicago; however, stormwater harvesting and reuse have been implemented in Chicago. Water-reuse systems currently

Table 1. Rooftops targeted for disconnection

Tier	Shaft	Total rooftop area (ft^2)
Tier 1	Shaft No. 3	280,000
Tier 2	Shaft No. 4	297,000
Tier 3	New Shaft No. 1	346,000
	New Shaft No. 2	308,000
	New Shaft No. 3	217,000
Total		1,448,000

Figure 7. Simulated tunnel fill-and-drain sequence



operating in Illinois have been approved on an individual basis by three agencies responsible for water-reuse projects: the Illinois Department of Public Health, which administers authority under the Illinois plumbing code; the city Department of Buildings, which administers authority under the Chicago building and plumbing codes and uses a green-permit program; and the Committee on Building Standards and Tests within the Department of Buildings.

Benefits of the tunnel

The concept of using an abandoned tunnel for stormwater capture and conveyance can be applied in other areas of the city. In fact, six additional abandoned water tunnels were identified in the same plan area as the Blue Island Avenue Tunnel.

The benefits of the stormwater capture and conveyance tunnel extend beyond removing impervious areas from the combined sewer system. Other potential effects of implementing this stormwater capture project include the following:

- ***Fewer basement backups.*** Storm flows removed from the combined system assist in preventing basement backups.
- ***Less surface ponding and flooding.*** Removing rooftop rainwater from the grid leaves room in the local sewer system and lowers the probability of surface flooding.
- ***Less flow to the combined system.*** Stormwater previously entering the local combined sewer system is taken off the grid.
- ***Fewer combined sewer overflows.*** Reducing storm flows can prevent existing infrastructure from being overwhelmed, reducing overflows to the river.
- ***Reduced potable water use.*** MWRD and CDWM benefit from reuse of harvested rainwater.
- ***Smaller carbon footprint.*** Removing stormwater from the local combined sewer system reduces pumping and treatment energy consumption at water resource recovery facilities.
- ***Public awareness and engagement.*** This project provides a platform for urban stakeholders to engage in a green infrastructure project, generating positive publicity for the city and the contributing stakeholders. The project would be a unique display of governmental agency collaboration and stakeholder participation in implementing green infrastructure and water conservation.

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Table 2. Stormwater capture summary

	Input location	Capture volume (million gal)		
		1 in. of rain	April 2013 storm (5.5 in. of rain)	Typical year (36 in. of rain)
Tier 1	Shaft No. 3	0.2	1.0	6.3
Tier 2	Shaft No. 4	0.2	1.0	6.7
Tier 3	New Drop Shaft No. 1	0.2	1.2	7.7
	New Drop Shaft No. 2	0.2	1.1	6.9
	New Drop Shaft No. 3	0.1	0.7	4.9
Total		0.9	5.0	32.5