In the search for a big-city refuge from climate change, Chicago looks like an excellent option. At least, it does on a map.

It stands a half-continent away from the threat of surging ocean levels. Its northern locale has protected it, to some extent, from southern heat waves. And droughts that threaten crops, forests and water supplies in so many places? Chicago hugs the shore of one of the grandest expanses of freshwater in the world.

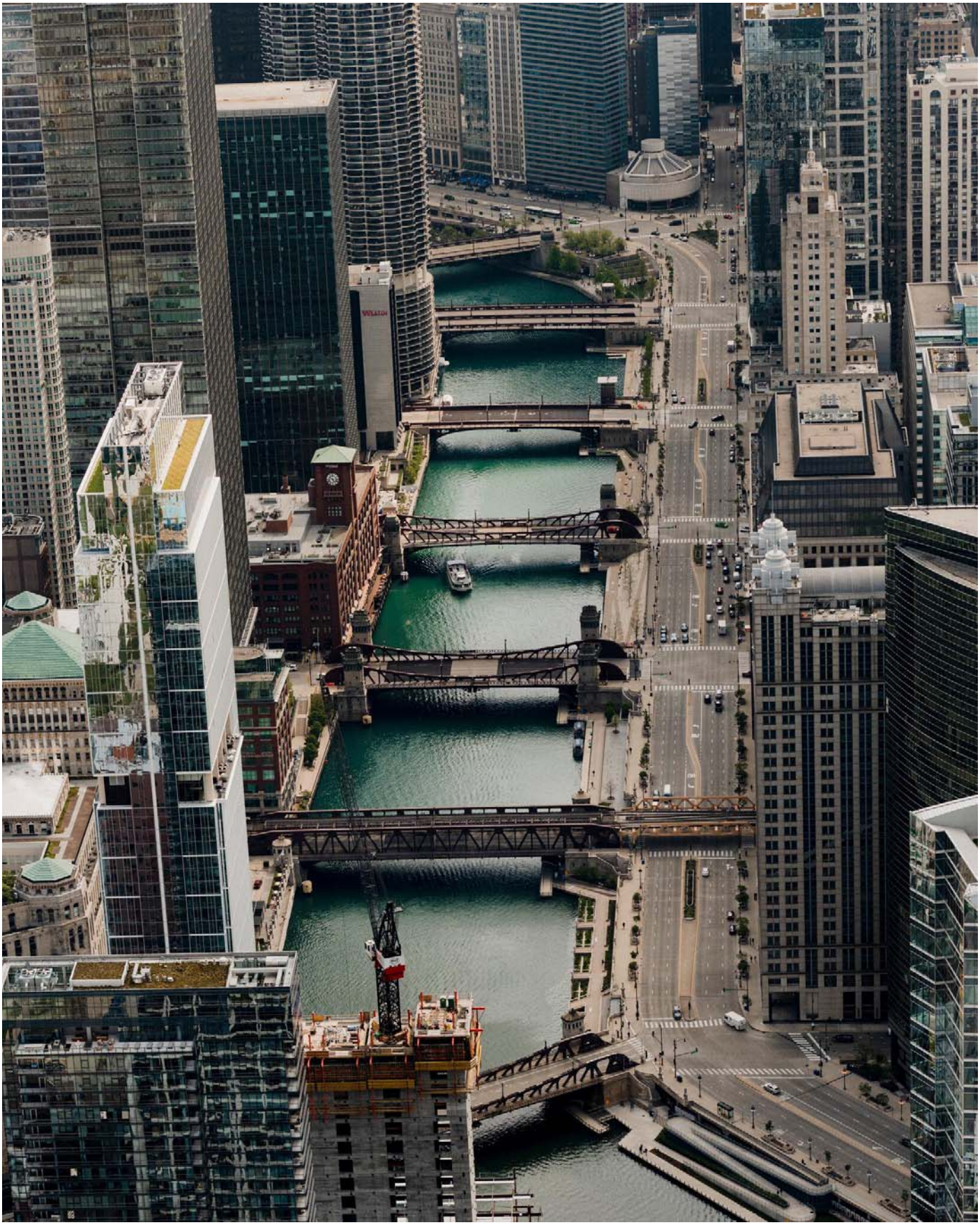
Water is, in fact, why Chicago exists. The nation's third-largest city grew from a remarkable geographical quirk, a small, swampy dip in a continental divide that separates two vast watersheds: the Great Lakes and the Mississippi River Basin. In the 19th century, Chicagoans dug a canal linking those two watersheds, transforming their muddy town into a metropolis of commerce by making the riches of the American Midwest accessible to the world.

The mule-drawn barges that worked its canals long ago gave way to trains, planes and eighteen-wheelers.

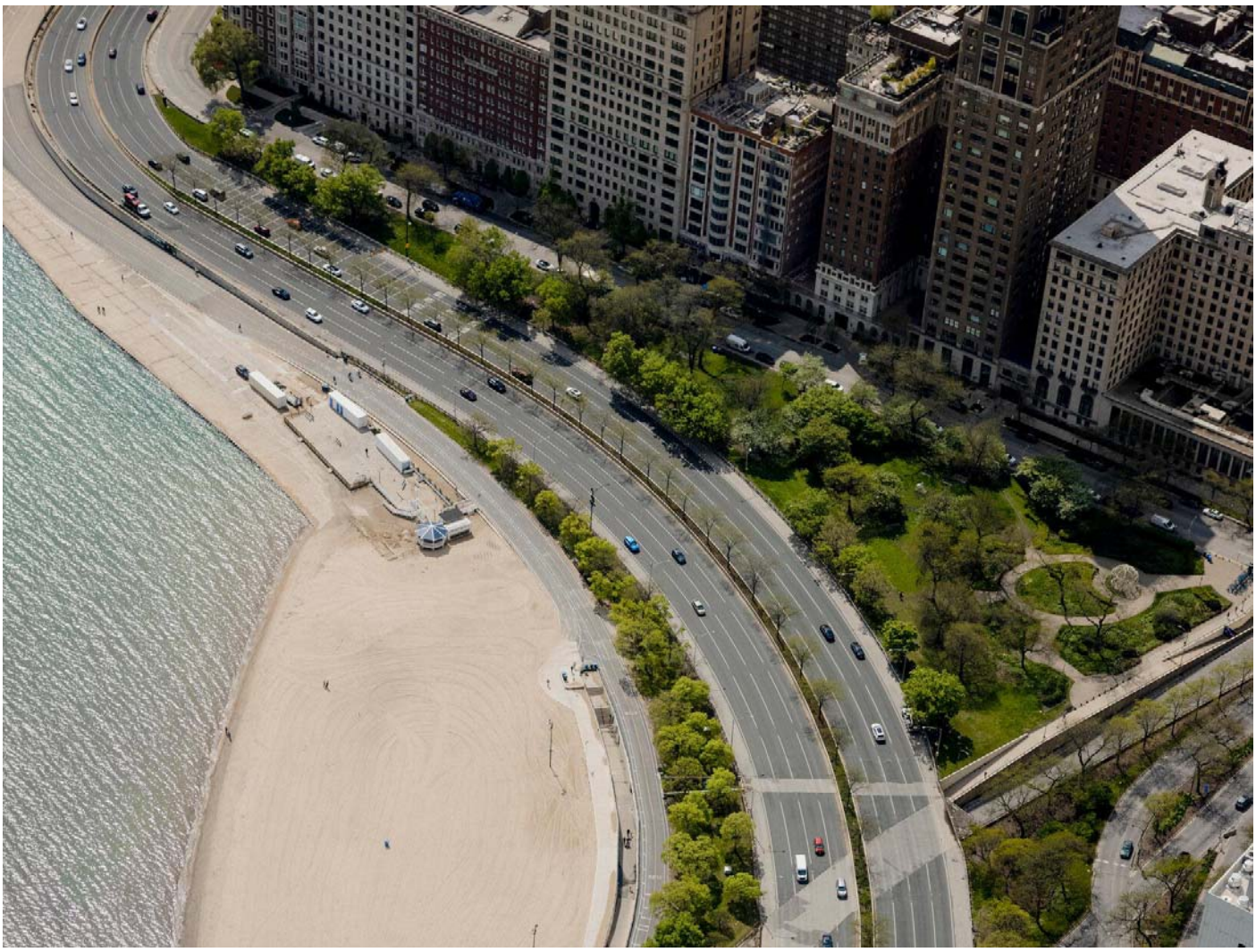
But the same waters that gave life to the city threaten it today, because Chicago is built on a shaky prospect — the idea that the swamp that was drained will stay tamed and that Lake Michigan's shoreline will remain in essentially the same place it's been for the past 300 years.

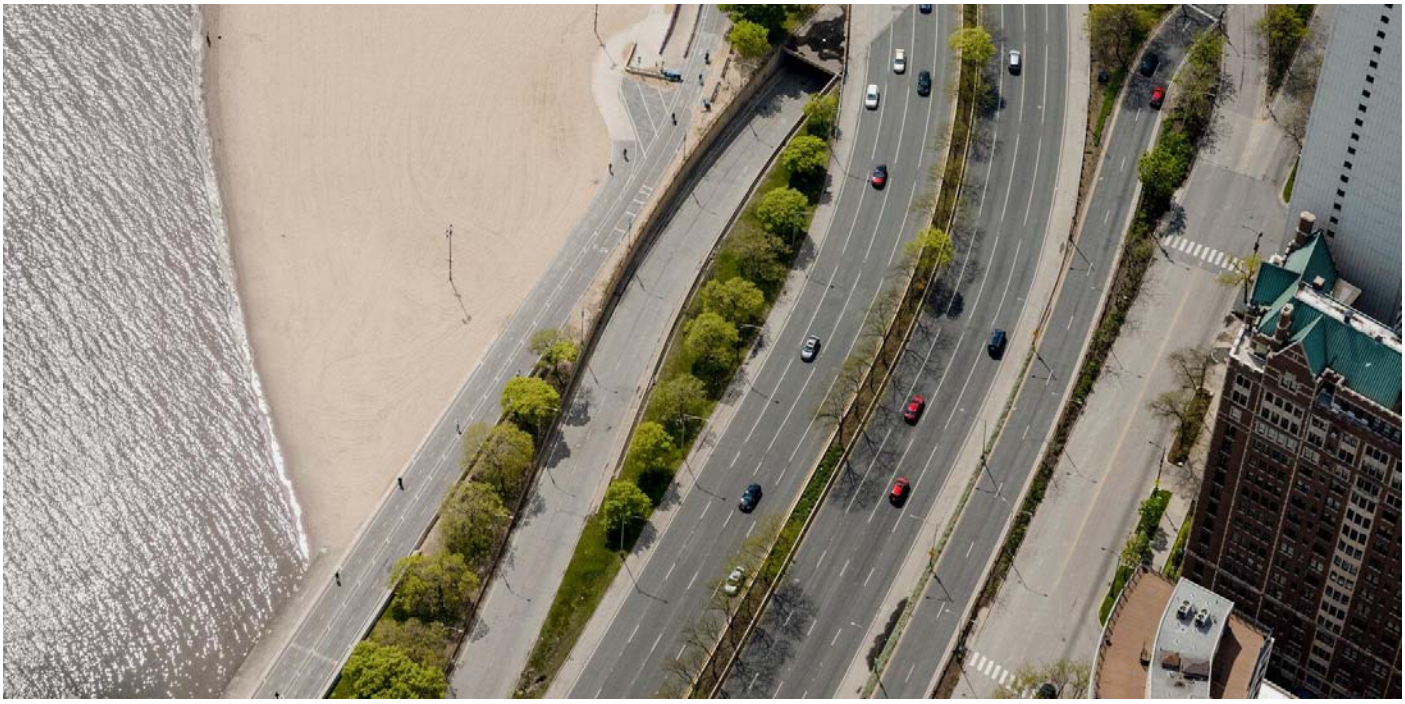
The lake may have other plans.

Climate change has started pushing Lake Michigan's water levels toward uncharted territory as patterns of rain, snowfall and evaporation are transformed by the warming world. The lake's high-water cycles are threatening to get higher; the lows lower. Already, the swings between the two show signs of happening faster than any time in recorded history.



The Chicago River





Lake Shore Drive

A series of ferocious storms in recent years has made it clear that the threat this poses to a metro area of 9.5 million people is not abstract.

“There are buildings just teetering on the edge of the lake. A few years ago, they had a beach. Now the water is lapping at their foundations,” Josh Ellis, a former vice president of Chicago’s 87-year-old, nonprofit Metropolitan Planning Council, said this year. “This is an existential problem for those neighborhoods and, ultimately, for the city.”

Jera Slaughter, who lives on the South Side, remembers a dramatic flood in 1987, when water washed through the ground floor of her apartment building. Back then, she said, everyone repeatedly was assured it was an aberration. “We were told, ‘You’ll never see this kind of water again in your lifetime,’” the 70-year-old retired Amtrak employee recalled in early May. “But it’s worse now.”

Lake Michigan’s water level has historically risen or fallen by just a matter of inches over the course of a year, swelling in summer following the spring snowmelt and falling off in winter. Bigger oscillations, a few feet up or down from the average, also took place in slow, almost rhythmic cycles unfolding over the course of decades.

No more.

In 2013, Lake Michigan plunged to a low not seen since record-keeping began in the mid-1800s, wreaking havoc across the Midwest. Marina docks became useless catwalks. Freighter captains couldn’t fully load their ships. And fears grew that the lake would drop so low it would no longer be able to feed the Chicago River, the defining waterway that snakes through the heart of the city.

That fear was short-lived. Just a year later, in 2014, the lake started climbing at a stunning rate, ultimately setting a record summertime high in 2020 before drought took hold and water levels started plunging again.

In just seven years, Lake Michigan had swung more than six feet. It was an ominous sign that the inland sea, yoked for centuries to its historic shoreline, is starting to buck.

A clash between elemental forces — sun, rain, heat and ice — is what is threatening to upend centuries of relative stability along the Great Lakes' 10,000 miles of shoreline, including the 22 miles that define Chicago's eastern edge. And the best explanation is climate change, said Drew Gronewold, a hydrologist at the University of Michigan who has been studying lake levels for more than a decade.

In fact, the speed and uncertainty of the changes underscore how Chicago, in some crucial ways, is perhaps more immediately exposed to the dangers of global warming than cities on the ocean. At least ocean levels change relatively slowly and predictably (storm surges notwithstanding) and move in just one direction: up.

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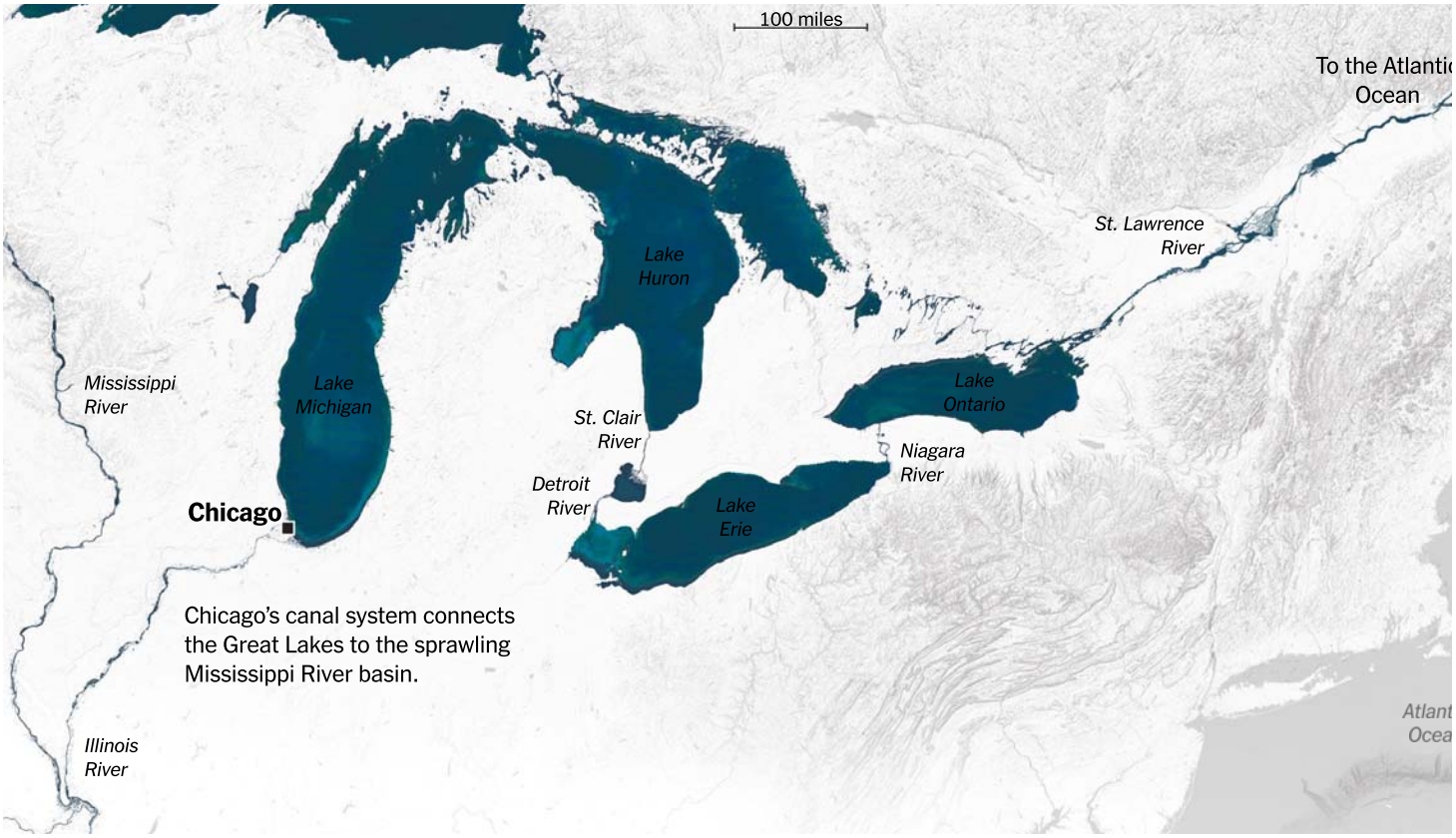
Because he grew up in New England, Dr. Gronewold said, he hadn't reckoned with the true immensity of the Great Lakes until the first time he climbed a sand dune towering hundreds of feet over Lake Michigan. It felt, he said, as if he were back standing on the Atlantic Coast of his native Maine.

"When you look out over the lake, you realize for the first time that you can't differentiate it from the ocean," he said. "You can't see land in any direction."

Oceanic vistas aside, the five connected Great Lakes function more like a slow-motion river flowing west to east, with each lake dumping into the next until their collective outflow is gathered in the St. Lawrence River and carried to the Atlantic Ocean.



Source: Water detected via Sentinel-2 short-wave infrared composite image

Like any river, that outflow must be replaced by inflows, and in this sense the lakes have historically operated like an exquisitely balanced bank account. Deposits take the form of precipitation: rain and snow. Withdrawals are measured in terms of water that flows outward to the ocean, along with the water that evaporates into the sky.

Dr. Gronewold's work is focused on what he calls an emerging tug of war between recent increases in both evaporation and precipitation, each of which can be influenced by the warming globe.

The hope is that these two clashing forces will ultimately balance each other out. The reality may be another story.

Gauges on the United States side of the border show the Great Lakes Basin has, since the 1990s, received far more precipitation than average. The past five years collectively have been the wettest half-decade on record.

It is likely no coincidence that the average air temperature in the same region has increased 1.2 degrees Fahrenheit since 1991. Warmer air factors into wetter weather, and a surging lake level, because it can hold more moisture.

But warmer air also means more evaporation.

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This is where the ice comes in. Even a slight air temperature increase can dramatically reduce the lake's winter ice cover. And because ice reflects the sun's heat, less ice means warmer water, which accelerates evaporation.

Between 1999 and 2013, evaporation appeared to be winning the tug of war. Over that time, Lake Michigan spent a record 15 years below its average level, despite greater precipitation.

In early 2013, the lake hit a record low.

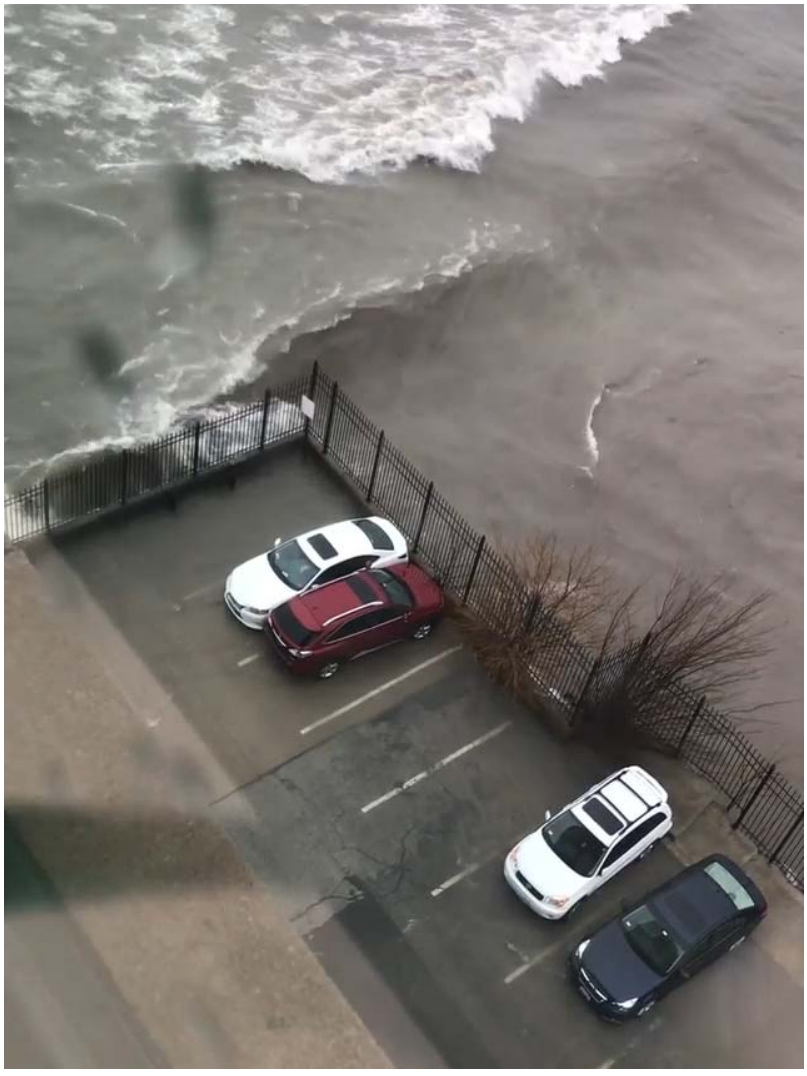
Then, yet another force of nature emerged: a weakening of the Polar Vortex.

Several brutally cold winters settled over the Great Lakes starting in 2014, driven in part by the destabilization of the famous swirl of frigid air around the North Pole. When the vortex's tight spin goes wobbly, it can send blasts of arctic air into the Great Lakes region for weeks on end. Many scientists believe this periodic weakening of the vortex may also be tied to a warming planet.

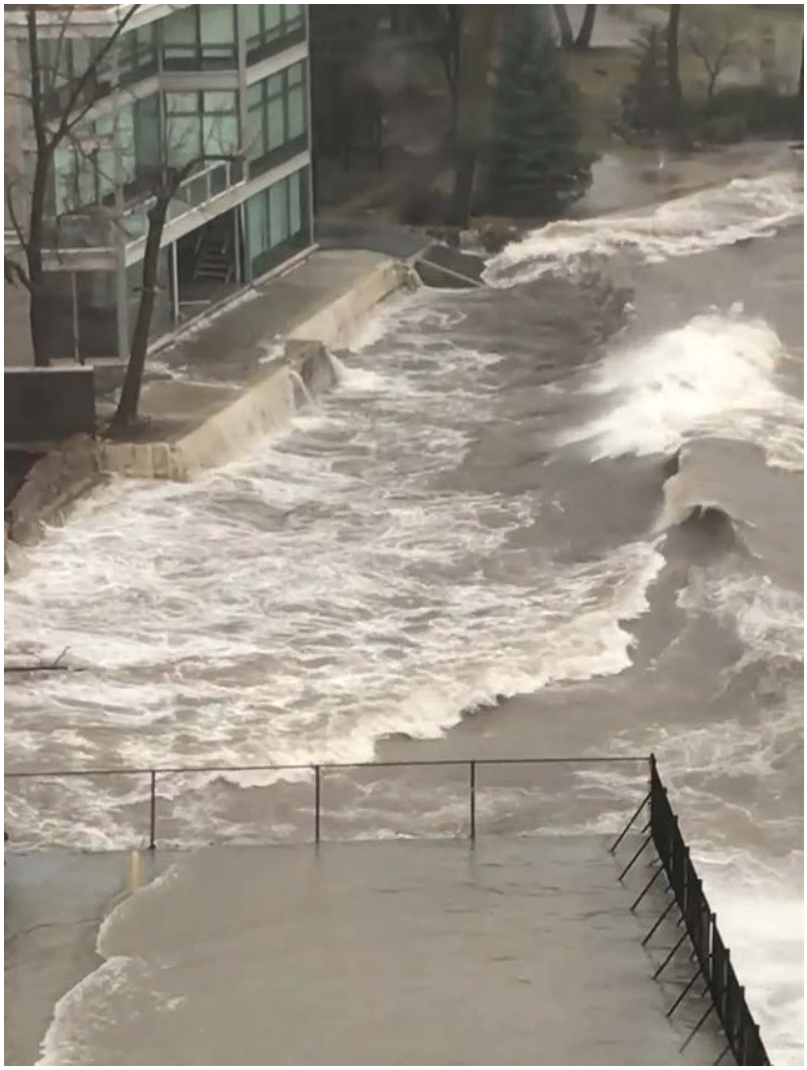
Whatever the case, the frigid blasts caused Lake Michigan's ice cover to surge for several winters. That lowered water temperatures and slowed evaporation — and helped drive the lake level to the record summertime high in 2020.

Chicagoans paid a heavy price.

Beloved sandy beaches disappeared. Wind-riled waters shattered living room glass and flooded apartment basements. Extreme storms turned city streets into rivers.



The morning of Jan. 11, 2020, on the lakeshore. Deborah Harrington



Battered homes, battered cars. Deborah Harrington

Since last fall, the lake has fallen about a foot because of a relatively mild winter and a continuing drought. But nobody knows where this is headed. If warmer winters persist, the increased evaporation could help to shrink the lake back into record-low territory.

Or lower.

“From the conversations I have with colleagues, the consistent message I hear is that we can expect extremes on both ends,” said John Allis, chief of the Army Corps of Engineers’ Great Lakes hydraulics and hydrology office.

If the lake were to drop just a couple of feet below its all-time low, or surge a couple of feet above its record high, the consequences for the city could be dire.

When Lake Michigan hit its low in 2013, conservationists warned it was very likely only a matter of time until the lake dropped so far in relation to the Chicago River that the river, which flows out of the lake and carries Chicago’s treated wastewater south toward the Gulf of Mexico, might actually reverse course and begin flowing into the lake — the city’s drinking-water source.

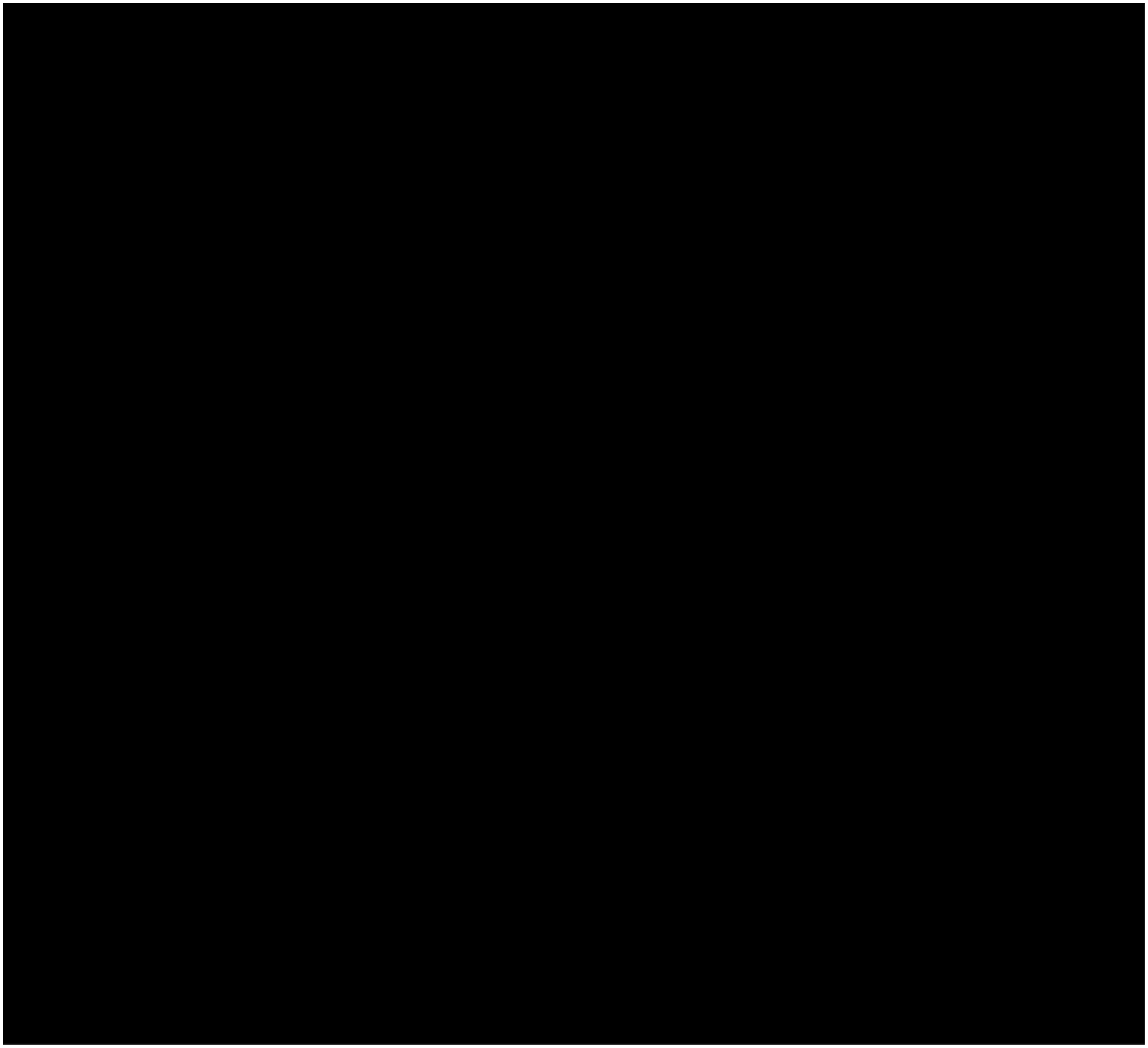
The estimate then was that the river could potentially reverse itself if the lake level dipped a mere six inches.

But then, just seven years later, high water was the problem.

Lake Michigan swells, and North Avenue Beach disappears. Google Earth

A city by the sea might “build for the future,” said Joel Brammeier, president of the Chicago-based conservation group Alliance for the Great Lakes. “Here, we don’t even know what that looks like.”

Throughout the first two centuries of its existence, Chicago became famous as a city that pushed water around like nowhere else. Now, in the ever-warming world of the 21st century, the water is starting to push back.



Chicago History Museum

In 1673, the Jesuit missionary Jacques Marquette and fellow explorer Louis Joliet, a philosophy student turned fur trader, became the first known Europeans to set eyes on what is today Chicago.

The two men were returning from a voyage down the Mississippi River. On their outbound trip, the expedition had to carry its canoes overland in Wisconsin. But on the return trip, Native Americans steered the explorers toward a shortcut back to the Great Lakes — a swamp now called Chicago.

In their natural state, the Mississippi River and Great Lakes basins were separated by a ridge in the landscape that kept the two basins' waters from mingling, just like the better-known Continental Divide that runs the dorsum of the Rockies and separates waters bound west for the Pacific from those flowing eastward.

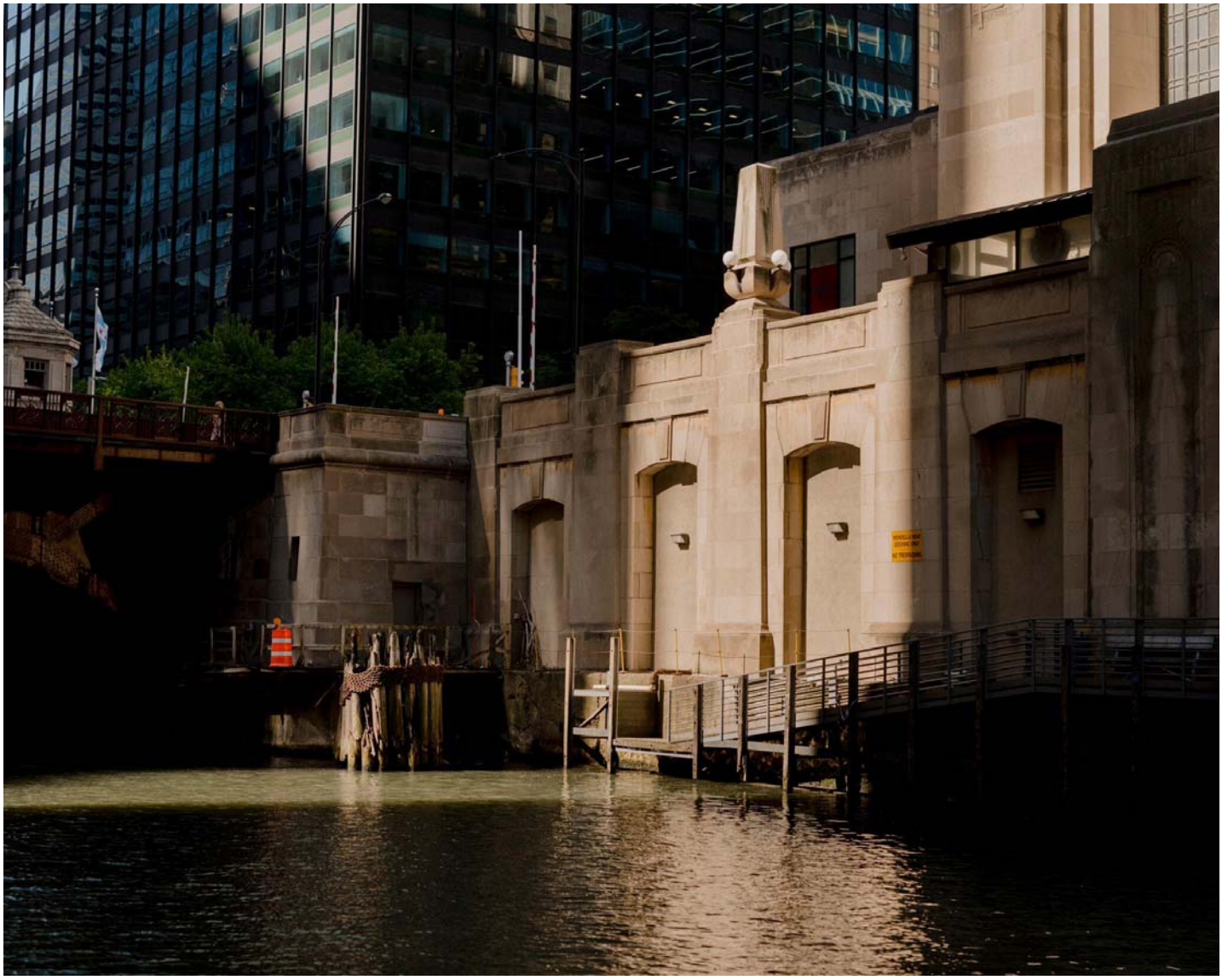
But the divide separating the Mississippi from the Great Lakes is nothing like a mountain range. In many places, it is a gently sweeping hill. In others, it's an imperceptible hump.

Chicago Lithographing Co., Library of Congress

And in Chicago it is, or was, a wetlands surrounding a shallow lake whose indolent outflows could, in periods of high water, drift in both directions — eastward toward Lake Michigan and westward into the Mississippi Basin. The explorers found that crossing between the two basins at this sag in the divide required only a relatively brief slog through the mud.

Joliet reported to French leaders back in Quebec that he had found a strategic oddity in the continental geography that "will hardly be believed." He saw the swamp as a gateway into the heart of America, opened simply by digging a roughly 1.5-mile channel across it so that vessels could float between the Mississippi Basin and the Great Lakes.

Construction of such a canal had to wait a century and a half, until 1836. But by 1870, the canal had helped propel Chicago from a mangy frontier outpost of less than 5,000 into a metropolis of 300,000. Along the way it became one of the nation's busiest ports, into which immigrants flooded and out of which flowed the bounty of the North American interior — furs, timber, grains and livestock.



City meets river: a water taxi stop.

But even as a metropolis rose from the mud, the flat landscape never went away. Storm and wastewater drainage in the young city was next to impossible, leaving streets smothered in a septic goo. In wet seasons, the quagmire was so deep it prompted signs along downtown streets issuing an ominous warning: “No bottom.”

“It was woe to the unlucky teamster who chanced to disregard the warning,” the Chicago Tribune wrote in 1859, “for generally his horse had to be dragged out by the neck.”

Chicago couldn’t fix this problem the way other cities did, by laying sloped sewers. The land was so low, it was impossible to place sewers below the streets and still have enough tilt to carry wastewater into the Chicago River.

Chicago History Museum

So, Chicago's leaders got creative. Instead of putting sewers under the streets, they put sewers on top of the streets, then built new roads atop the old ones. They effectively hoisted the city out of the swamp.

Buildings in downtown were raised by as much as eight feet, an enterprise that required placing immense beams and jackscrews beneath their foundations. Then, a conductor would direct hundreds of laborers in the precisely choreographed turns of the screws to lift the structures out of the muck.

"The superintendent takes his stand," the Chicago Tribune wrote at the time, and with a "shrill whistle" directs the crew to begin. "He continues his whistle long enough for every man to turn each screw one complete round of the thread. Thus the building is raised at every point precisely at the same moment."

It was a feat of engineering as audacious as it was ultimately ineffective at solving Chicago's predicament.

While jacking up Chicago to make room for sewers may have solved one predicament — the filthy, impassable streets — it caused another. All the sewage still flowed into the Chicago River. And the river still flowed into the lake, the city's drinking-water source.

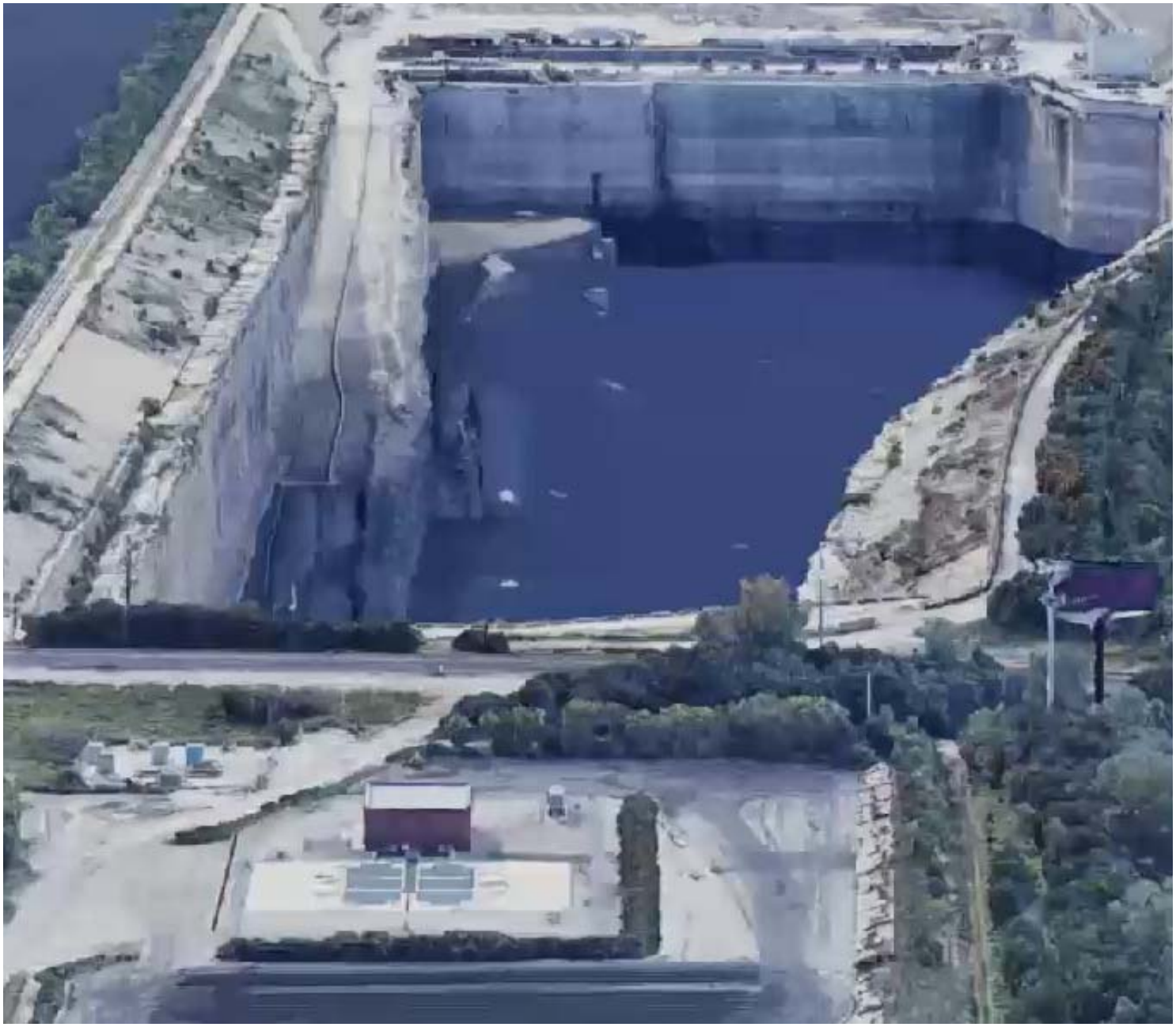
Desperate to protect residents from waterborne scourges like cholera, city leaders at the end of the 19th century hatched another audacious plan: Reverse the direction of the river so it flowed away from Lake Michigan instead of into it.

They achieved this by dynamiting a 28-mile-long canal connecting the Chicago River to the Des Plaines River, which flows toward the Mississippi. It was a project typical of a city that, as one author described in 1898, "stands as a stupendous piece of blasphemy against nature."

The Chicago River passes through the heart of the city.

Designed as an immense drain to flush away wastewater, it runs as straight as an interstate highway. It can flow in both directions.

Today, Chicago is still fighting to put water in its place. An expanding network of vast lagoons captures sewer overflows that plague the city.



Sources: Satellite images are from NOAA, TerraMetric and Landsat/ Copernicus via Google Earth Studio

The Chicago Sanitary and Ship Canal opened in 1900, a feat of engineering 160 feet wide and 25 feet deep and, importantly, lower than Lake Michigan. So gravity dictated that the Chicago River would henceforth flow in the opposite direction.

Today, on the Chicago waterfront stands the Harbor Lock, a set of mammoth steel gates separating lake water from river water. It marks the spot where boats pass between the Great Lakes Basin and the Mississippi Basin. Chicago has, essentially, fashioned for itself a manmade continental divide, with hinges.

It is Joliet's dream, realized on a scale he never could have fathomed.

For most of the 121 years since it opened, the river and canal, the centerpiece of the city's huge manmade waterway system, functioned just as its designers had hoped. It reversed the city's namesake river, sending wastewater toward the Gulf of Mexico and away from the city's drinking-water intake pipes on Lake Michigan.

Usually, but not always.

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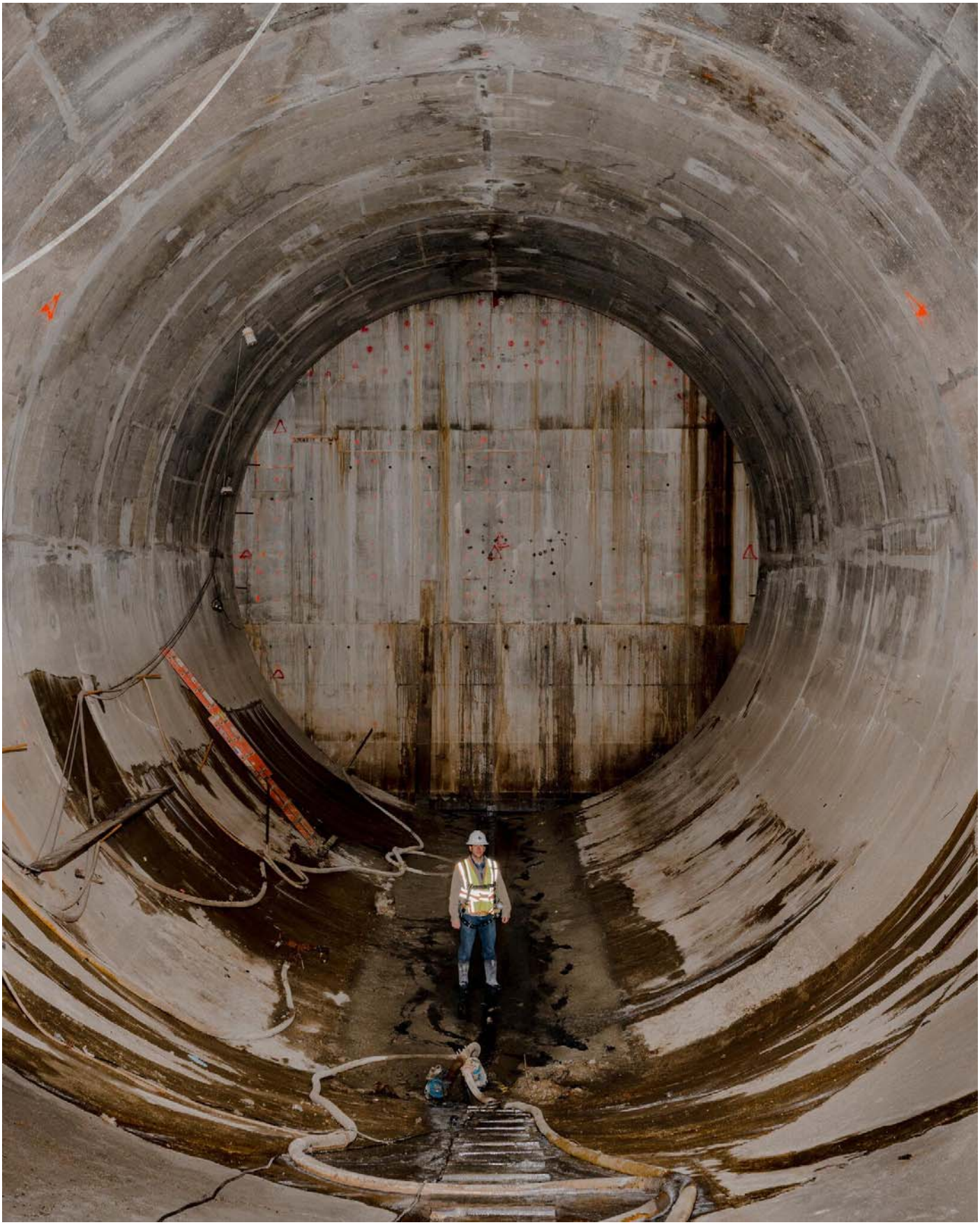
Throughout much of the 20th century, storm-loaded sewers regularly overwhelmed Chicago's sewage treatment plants, resulting in storm water and sewage (Chicago's old-fashioned sewers carry both) being dumped straight into the river and canal.

But in the heaviest storms, even the river and canal system could get overwhelmed. Which left two bad choices: Let the river and canal overtop their banks and flood city streets with sewage, or open the lock gates so the swollen, polluted river could again, albeit temporarily, tumble into Lake Michigan.

Once more, the city was forced to try to dig itself out of a fix.



Cavernous sewage-storage tunnels.

A vast reservoir under construction.

Since the 1970s, Chicago has been constructing a multibillion-dollar system of sewage-storage tunnels and reservoirs. The idea is that, when rainstorms hit, the extra runoff can be safely warehoused. Once a storm

subsides, all that storm water and raw sewage can be slowly treated and released, avoiding floods and also avoiding the release of untreated filth into the lake.

The tunnels, some a yawning 33 feet in diameter and running up to 300 feet below city streets, stretch 109 miles and collectively hold 2.3 billion gallons of water. A network of reservoirs holds roughly an additional 12 billion gallons and, once the entire project is completed by decade's end, it will have the capacity to hold more than 20 billion gallons.

How big is that? Imagine a 30-foot-deep sewer lagoon roughly the size of two-and-a-half New York City Central Parks.

While the system has dramatically increased water quality in the river and lake, it's still not big enough to handle the worst storms. To help soak up downpours, open spaces are also being built, as well as green roofs and porous parking lots. But they, too, aren't enough.

This forces Chicago to continue to rely on opening the navigation lock, along with some nearby gates, as a safety valve to send pulses of storm-driven wastewater into Lake Michigan.

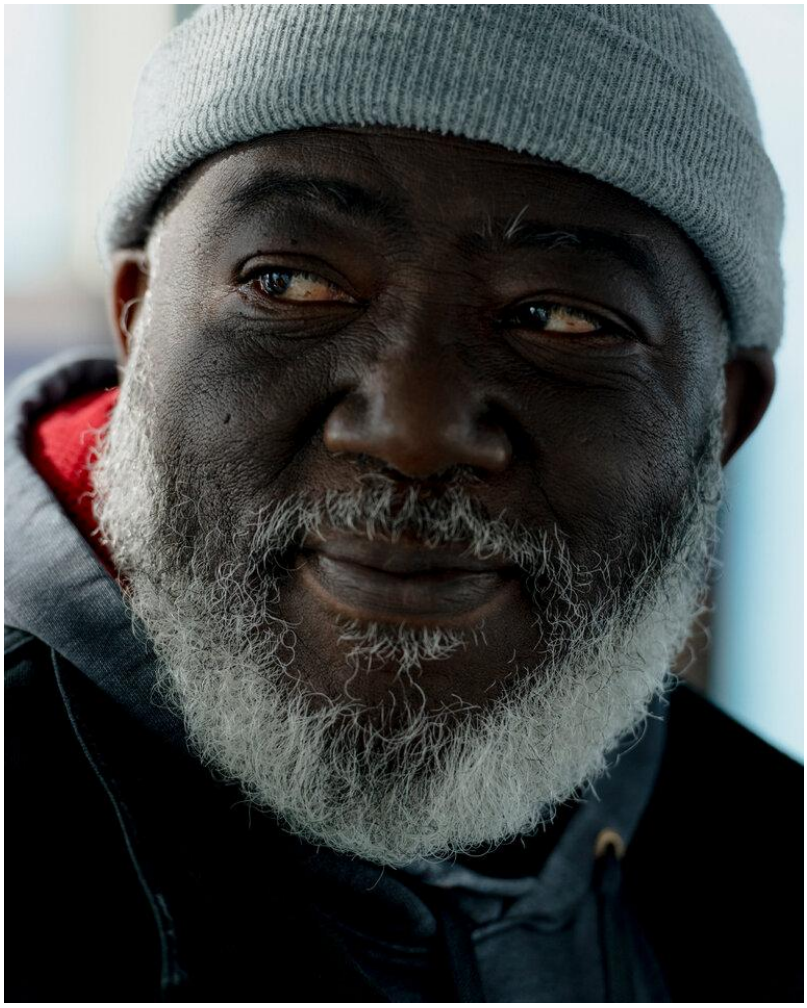
In this way, Lake Michigan has been there to rescue Chicago in its most dire times of need. For more than a century — through generations of blasting, tunneling, jacking and remaking of a swamp to match a city's ambitions — the lake was ready to serve as a last-resort dump for sewage.

Then came May 17, 2020.

That afternoon Tyrone Valley, lockmaster at Chicago Harbor, got a call. There was big trouble brewing in the river.

Mr. Valley, 56 years old, had just worked an overnight shift at the lock, and he was looking forward to having the week off. But his crew needed him back because the rains that had been pounding the city for three days were threatening Chicago in a fashion no one had experienced.

He hopped into his red Ford F-150 and started the hourlong drive back from his home in Joliet (yes, named after that Joliet). Along the way, his crew called him with alarming updates: Water was rising menacingly fast against the riverbanks in the heart of Chicago. “There were a few curse words exchanged on that drive,” Mr. Valley recalled.



Tyrone Valley, lockmaster.

River managers have a trigger point for opening the lock gates — reversing the river's flow into Lake Michigan — in order to protect downtown Chicago from disaster. That trigger is typically 3.5 feet above Chicago's official ground level, which, in the universe of river managers, is considered 0 feet.

Normally the river, as measured on giant white rulers tiled on the lock's walls, ranges between 2 and 3 feet below ground level. That's about where it had been when Mr. Valley had headed home that morning.

But there was a problem.

Three days earlier, a relentless storm had dropped a record 24-hour rainfall for that date. The tunnels and reservoirs had done their job helping to contain the deluge. But then, a second storm hit while the reservoirs were still holding water from the first storm.

That meant the storm water and sewage had to be released straight to the river. And it was too much for the river to handle.

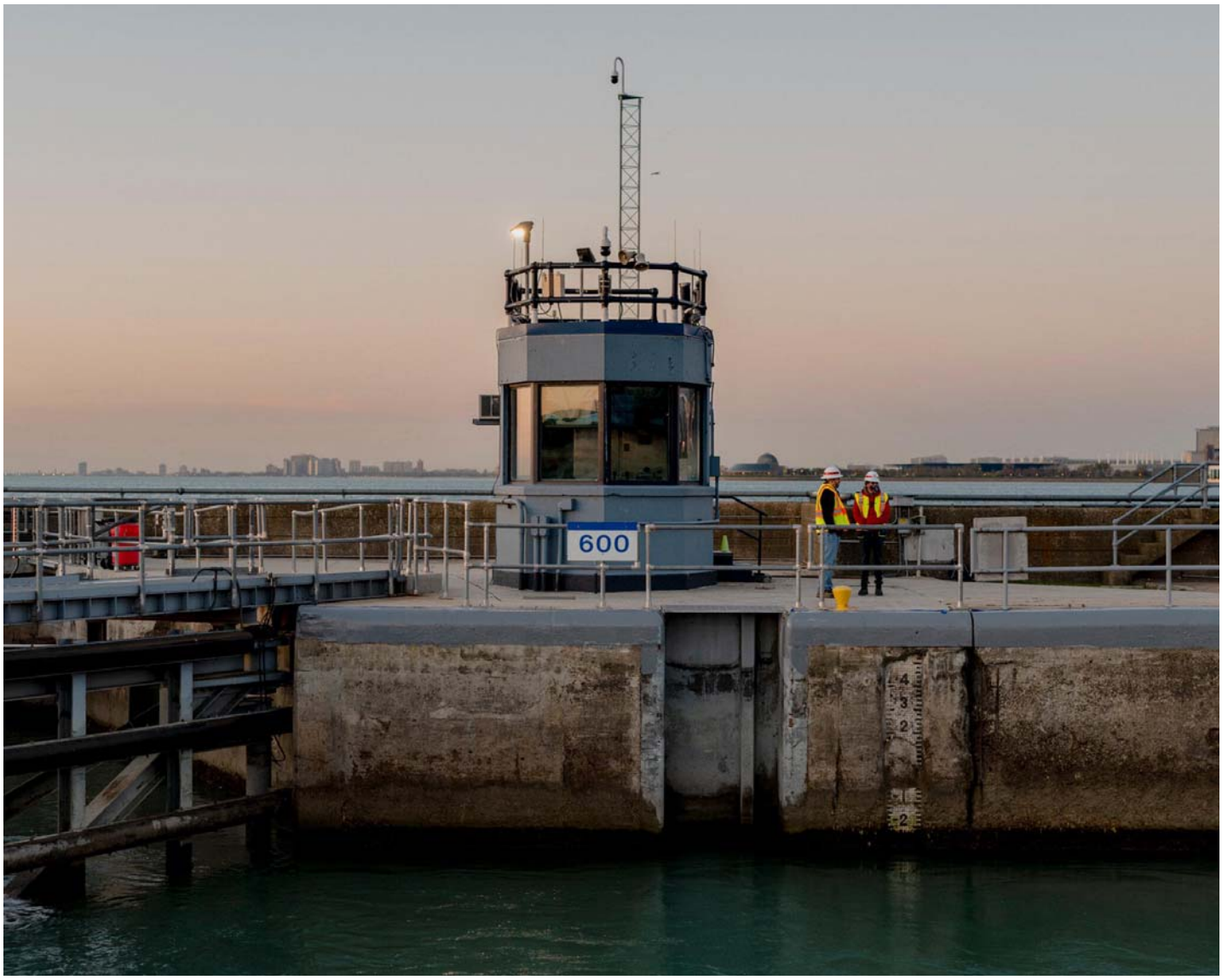
By 5:23 p.m. the river level hit +3.5 feet, the point under normal conditions to open the lock gates and reverse the river into Lake Michigan. Messy, yes. But not as messy as letting sewage-laced water pour into downtown. However, this time conditions weren't normal.

Lake Michigan's level at that moment was at a record high for May — well above the river. So opening the lock wasn't an option, because that would have sent lake water pouring into the river, flooding the city.

At 6:16 p.m. the river hit +3.8 feet. Then, less than 10 minutes later, it hit +4 feet, a number “we thought we’d never see,” said James Duncker, a hydrologist with the United States Geological Survey.

At that moment, Mr. Valley was standing along the lock wall, helpless. The sewage-laced muck smelled “like rotten eggs,” he said.

Then, at 6:54 p.m. the river surged to +4.6 feet, putting it about five inches above the level of the lake. Finally, Mr. Valley had options again.



Testing the lock at Chicago Harbor.

He gave the order, and his crew opened the immense steel lock gates. A whoosh of water carrying all manner of waste — trees, chunks of dock, litter, toilet flushes — blasted into Lake Michigan.

In mere minutes, the suddenly reversed river, roaring like a freight train, dropped below lake level. This was a new problem; If the gates stayed open, lake water would slosh back into the river, further flooding the city.

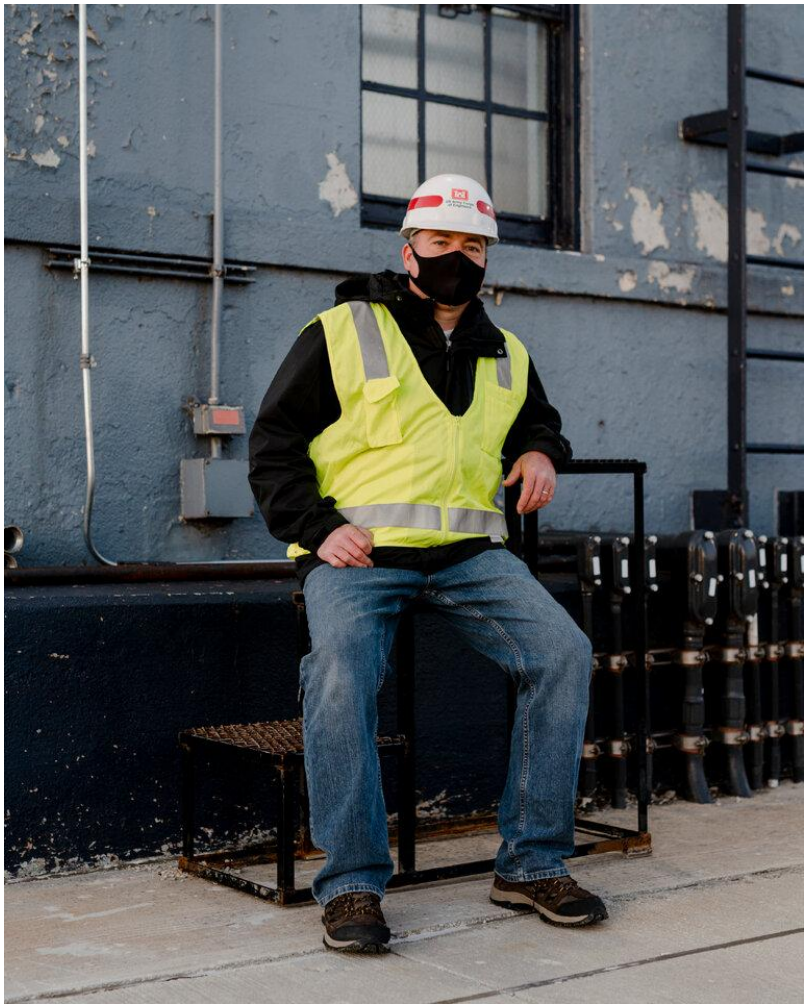
There was nothing in the playbook for this scenario. Mr. Valley and the lock operators had to wing it, pinching the gates closed to let the river again rise above the lake, then swinging them open again to let the swollen river drain into the lake.

Again and again, the crew repeated these steps. They were, almost literally, bailing out a flooding downtown Chicago by flapping the steel gates.

“We just did it on the fly,” Mr. Valley said.

Still, it was not enough. The river kept climbing, eventually peaking at +5.12 feet a little after 7 p.m.

The resulting floodwaters not only submerged the bustling Lower Wacker Drive, one of the city’s main arteries, but also knocked out the electrical power at the nearby Willis Tower (formerly the Sears Tower) all the way up to the aircraft warning lights atop its tusk-like antennas. A city hotline fielded more than 1,500 distress calls from residents whose basements were flooded.



Joel Schmidt, hydraulic engineer.

Flooding isn’t new in Chicago. But this time was different: Lake Michigan wasn’t at the ready to function as an oversized emergency retention pond.

It may not be the last time.

Paul Roebber, a meteorologist with the University of Wisconsin-Milwaukee, has run computer simulations that show the potential for the lake to break last year’s record summertime highs by as much as two feet, if the weather stays wet enough long enough. Another study looked backward, using carbon dating to examine Lake Michigan’s high points during the era of the Egyptian pharaohs, 4,500 years ago. It showed the lake was roughly nine feet higher than its modern long-term average.

That was during a post-glacial period, hydrologists point out, when the lake was seeking a steady state. Changing weather patterns hint that it still is.

Six months after the flood, Mr. Valley and Joel Schmidt, an Army Corps hydraulic engineer, stood on the steel deck above the lock gates and looked down as Lake Michigan splashed against them. They explained that the extreme high water in the lake during the May 2020 flood was partly due to a wind-driven surge that pushed up water levels along Chicago's shoreline by almost one foot.

That's not unusual; even two-foot storm surges aren't uncommon. But it perfectly captures the city's delicate balance between dryness and disaster.

If a two-foot storm surge were to strike when the lake level was just a couple of feet higher, the lock itself would in effect be useless. Lake water would overtop its gates and race into the city, and beyond. "It would be a problem," Mr. Schmidt said as waves crashed nearby. "It would be a big problem."

Added Mr. Valley: "All the way down to the Mississippi."

Cheryl Watson remembers the basement of her brick bungalow on the South Side as a place to play ping pong, to roller skate and, when it rained, to fear.

Not only can she still picture her father and brothers descending the steps in galoshes, carrying squeegees and bleach to clean up the dangerous, sewage-laced water that regularly bubbled from the basement drain, she can smell it.

“It was dark water, green-looking,” she said of the putrid stew. “You didn’t quite know what it was, but you saw things floating in it.”

In Chicago, sometimes the threat of water comes from the sky. Sometimes it comes from the lake. And sometimes it comes from below.

When it rains, the city’s aged sewer system can be overwhelmed even before the immense storage tunnels and reservoirs hit capacity. The result is sewer backups that spout polluted water into basements and onto city streets. It is a problem that is particularly acute in some of Chicago’s impoverished, low-lying South Side neighborhoods where basements commonly double as bedrooms and play areas.

Ms. Watson, who is 66, today still lives in the same home. And the sewer backups that she remembers from childhood continue to plague her Chatham neighborhood.

Cheryl Watson on the South Side.

Though basement floods can be triggered by only moderate rains, they're much worse when big rains hit. And big rains are hitting increasingly often, particularly in spring.

Chicago's historic average for precipitation for May, 4.49 inches, was spectacularly eclipsed in May 2018 when a record 8.21 inches of rain fell. That record lasted just one year: In May 2019, 8.25 inches soaked the city. Then in May 2020, another record, 9.51 inches, swamped Chicago.

Ms. Watson has spent thousands of dollars on drain tiles that channel water to her sump pump, along with a special valve to block sewer backups. Yet she still suffers occasional flooding. Now, storm water often pools in her yard, then drains into her house.

One sign of the ubiquity of the problem: Chicago has a dedicated hotline for basement flooding. But even calls to the hotline probably don't capture the true scale of the crisis, Ms. Watson said.

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“If you report to the city, and word gets out, people fear it’s going to devalue their home,” she said. As a result, many of her neighbors keep their suffering to themselves. A truer measure, Ms. Watson said, are the mountains of toys, electronics, furniture and carpets that pile up in South Side alleys after the rains.

Then there are the floods triggered by the lake itself, one of the most severe of which struck in winter 1987 when gale-driven waves and a near-record-high lake level combined to submerge Lake Shore Drive. Tremendous waves battered Chicago’s coastline and “ground up giant concrete barriers as if they were coffee beans,” a journalist wrote at the time.

Jera Slaughter

Rock piles, sandbags awaiting future floods.

That turned out to be but a prelude to what the 21st century would bring.

Beginning in fall 2019, a series of storms ravaged the neighborhoods that pocket Chicago's mostly public shoreline. Nowhere has the lake been more menacing to lakefront property owners than the working-class

neighborhood along South Shore Drive, about 10 miles south of downtown, where Ms. Slaughter lives — the neighborhood where she rode out the 1987 storm that everyone back then dismissed as once-in-a-lifetime.

Today, her 13-story building's lakeside terrace resembles a war zone. Patio furniture has been swapped for sandbags, concrete blocks the size of washing machines and highway-style Jersey barriers. Yet the fortifications have proven a feeble match for breakers that can push around the hunks of concrete and can float 3,000-pound cars like bars of soap in a bathtub.

In the 1987 flood, Ms. Slaughter mostly worried about making it through the inconvenience of the basement flooding and the temporary loss of power. Now, she is concerned that the relentless waves may cause structural damage to her nearly 100-year-old building, which is listed on the National Register of Historic Places. "The damage and destruction is where the terror lies," she said. "We fear it is eating into our foundation."

The cost of climate change for Ms. Slaughter and her neighbors is not theoretical. The building's existing floodwater fortifications, along with a study exploring a more permanent offshore breakwater to dissipate the force of the surf, have already cost the co-op's residents some $450,000.

She and her neighbors are now waiting to learn whether they will receive government funds for the offshore barrier. Because without it, she said, their building, their home, is that barrier.

A barrier protecting South Shore Drive, and the city beyond.

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The harbor lighthouse, gateway to the heart of Chicago.