

Miami's fight against rising seas

By Amanda Ruggeri

4 April 2017

The first time my father's basement flooded, it was shortly after he moved in. The building was an ocean-front high-rise in a small city north of Miami called Sunny Isles Beach. The marble lobby had a waterfall that never stopped running; crisp-shirted valets parked your car for you. For the residents who lived in the more lavish flats, these cars were often BMWs and Mercedes. But no matter their value, the cars all wound up in the same place: the basement.

When I called, I'd ask my dad how the building was doing. "The basement flooded again a couple weeks ago," he'd sometimes say. Or: "It's getting worse." It's not only his building: he's also driven through a foot of water on a main road a couple of towns over and is used to tiptoeing around pools in the local supermarket's car park.

Ask nearly anyone in the Miami area about flooding and they'll have an anecdote to share. Many will also tell you that it's happening more and more frequently. The data backs them up.

It's easy to think that the only communities suffering from sea level rise are far-flung and remote. And while places like the Solomon Islands and Kiribati are indeed facing particularly dramatic challenges, they aren't the only ones being forced to grapple with the issue. Sea levels are rising around the world, and in the US, south Florida is ground zero – as much for the adaptation strategies it is attempting as for the risk that it bears.

One reason is that water levels here are rising especially quickly. The most frequently-used range of estimates puts the likely range between 15-25cm (6-10in) above 1992 levels by 2030, and 79-155cm (31-61in) by 2100. With tides higher than they have been in decades – and far higher than when this swampy, tropical corner of the US began to be drained and built on a century ago – many of south Florida's

drainage systems and seawalls are no longer enough. That means not only more flooding, but challenges for the infrastructure that residents depend on every day, from septic tanks to wells. “The consequences of sea level rise are going to occur way before the high tide reaches your doorstep,” says William Sweet, an oceanographer at the National Oceanic and Atmospheric Administration (NOAA).

The flooding would be a challenge for any community, but it poses particular risks here. One recent report estimated that Miami has the most to lose in terms of financial assets of any coastal city in the world, just above Guangzhou, China and New York City. This 120-mile (193km) corridor running up the coast from Homestead to Jupiter – taking in major cities like Miami, Fort Lauderdale and West Palm Beach – is the eighth most populous metropolitan area in the US. It’s also booming. In 2015, the US Census Bureau found that the population of all three counties here was growing – along with the rest of Florida – at around 8%, roughly twice the pace of the US average. Recent studies have shown that Florida has more residents at risk from climate change than any other US state.

It has more property at risk, too. In Miami-Dade County, developers had 1.6 million sq ft (149,000 sq m) of office space and 1.8 million of retail space under construction in the second quarter of 2016 alone. Sunny Isles Beach, home to 20,300 people, has eight high-rise buildings under construction; swing a seagull in the air, and you’ll hit a crane. As you might imagine, the value of development in this sun-soaked part of the country is high, too. Property in Sunny Isles alone is now worth more than \$10 billion. Many of the wealthiest people in the US reside in Florida, including 40 billionaires on the Forbes 400 list of richest Americans; on a recent week, the most expensive real estate listing in the US was a \$54 million mansion in Palm Beach.

Despite his history of referring to climate change as a “hoax” and his recent rollback of emissions-slashing initiatives, President Donald Trump is one of these property owners with a stake in the issue. The president frequently visits his Mar-a-Lago estate in Palm Beach, 75 miles (121km) north of Miami, which is itself an area experiencing flooding from high tides. There also are six Trump-branded residential buildings in Sunny Isles, one of which still provides the president with income, and a Trump-branded condominium complex in Hollywood.

Look beyond all the glass and steel, though, and – despite the federal government’s sidelining of the issue – there’s another thrum of activity. It’s the wastewater treatment plant constructing new buildings five feet higher than the old ones. The 105 miles (169km) of roads being raised in Miami Beach. The new shopping mall built with flood gates. The 116 tidal valves installed in Fort Lauderdale. The seawalls being raised

and repaired. And the worried conversations between more and more residents every year about what the sea-rise models predict – and what to do about it.

The communities aren't short of solutions. "Nobody's doing better adaptation work in the country than south Florida," says Daniel Kreeger, executive director of the nonprofit Association of Climate Change Officers. But the question isn't whether this work will save every community: it won't. Even those tasked with making their cities resilient admit that, at some point in the future, certain areas here will no longer be "viable" places to live. Rather, the challenge is to do enough to ensure that the economy as a whole continues to thrive and that tourists still come to enjoy the sun, sand – and swelling sea.

It's a challenge that many officials and experts are determined to meet. Getting there, though, requires a shift in how everyone from mayors to taxpayers, insurers to engineers, property developers to urban planners thinks about their communities – and the everyday decisions that shape them. The eyes of the world are on them: if one of the richest communities on the planet can't step up, what hope is there for everyone else?

"If the science is correct on this – which it is going to be – the question is, 'How extreme are the implications?'" says Kreeger. "We are literally going to have to rewrite how businesses function, and how cities are designed. Everything's going to change. And that's particularly going to be exacerbated in coastal communities.

"This would be no different than if I came to you and said 'Hey, in 40 years, gravity's going to change. I can't tell you exactly what it's going to be. But let's assume roughly between 50% and 80% stronger or weaker than it is now.' You'd look around and say 'Shoot, what's that going to affect?'

"And the answer is: it affects everything."

Sea level rise is global. But due to a variety of factors – including, for this part of the Atlantic coast, a likely weakening of the Gulf Stream, itself potentially a result of the melting of Greenland's ice caps – south Floridians are feeling the effects more than many others. While there has been a mean rise of a little more than 3mm per year worldwide since the 1990s, in the last decade, the NOAA Virginia Key tide gauge just south of Miami Beach has measured a 9mm rise annually.

That may not sound like much. But as an average, it doesn't tell the whole story of what residents see – including more extreme events like king tides (extremely high

tides), which have been getting dramatically higher. What's more, when you're talking about places like Miami Beach – where, as chief resiliency officer Susanne Torriente jokes, the elevation ranges between “flat and flatter” – every millimetre counts. Most of Miami Beach's built environment sits at an elevation of 60-120cm (2-6ft). And across the region, underground infrastructure – like aquifers or septic tanks – lies even closer to the water table.

On a nearly two-hour tour of Fort Lauderdale's adaptation strategies, the city's head of sustainability, Nancy Gassman, points out incremental differences in elevation: slight rolls in the sidewalk or paving that usually go unnoticed. “That might seem weird that I'm pointing out a couple of feet difference,” she says. “But a couple feet in south Florida – it's time. Elevation is time for us.”

Not only are sea levels rising, but the pace seems to be accelerating. That's been noted before – but what it means for south Florida was only recently brought home in a University of Miami study. “After 2006, sea level rose faster than before – and much faster than the global rate,” says the lead author Shimon Wdowinski, who is now with Miami's Florida International University. From 3mm per year from 1998 to 2005, the rise off Miami Beach tripled to that 9mm rate from 2006.

An uptick also happened between the 1930s and 1950s, says Wdowinski, making some question whether this is a similar oscillation. But that's probably wishful thinking. “It's not necessarily what we see now. This warming of the planet has been growing for a while,” he says. “It's probably a different process than what happened 60 years ago.”

One graph compiled in 2015 by the Southeast Florida Regional Climate Change Compact, a non-partisan initiative that collates expertise and coordinates efforts across Broward, Miami-Dade, Monroe and Palm Beach counties, is especially revealing (see below). At the bottom is a dotted green line, which rises slowly. Before you get optimistic, the footnote is firm: “This scenario would require significant reductions in greenhouse gas emissions in order to be plausible and does not reflect current emissions trends.” More probable is the range in the middle, shaded blue, which shows that a 6-10in (15-25cm) rise above 1992 levels is likely by 2030. At the top, the orange line is more severe still, going off the chart – to 81 inches (206cm) – by the end of the century.

“Can we definitely say it's the ocean warming?” says Sweet, who has authored several sea-level rise studies. “No. But is it indicative of what we'd expect to see? Yes.”

Modelling specific future scenarios is difficult – partly because scientists are still collecting and analysing data, partly because there are so many variables. What if the US or China reverses its trend on stabilising emissions? What if a major volcano erupts? What if a glacier melts more quickly than expected? But enough credible projections have been done to put together a range of scenarios that researchers are confident about.

One graph compiled in 2015 by the Southeast Florida Regional Climate Change Compact, a non-partisan initiative that collates expertise and coordinates efforts across Broward, Miami-Dade, Monroe and Palm Beach counties, is especially revealing (see below). At the bottom is a dotted green line, which rises slowly. Before you get optimistic, the footnote is firm: “This scenario would require significant reductions in greenhouse gas emissions in order to be plausible and does not reflect current emissions trends.” More probable is the range in the middle, shaded blue, which shows that a 6-10in (15-25cm) rise above 1992 levels is likely by 2030. At the top, the orange line is more severe still, going off the chart – to 81 inches (206cm) – by the end of the century.

But as more data comes in, even the worst-case estimates may turn out to be too low: for example, researchers recently discovered that ice is melting more rapidly than expected from both Antarctica and Greenland, plus gained a better understanding of how melting ice sheets actually affect sea-level rise. “The unlikely scenarios are now, all of a sudden, becoming more probable than they once were thought to be,” says Sweet.

The most dramatic impacts may not be felt for 50 or 100 years. But coastal communities are already experiencing more storms and extremely high tides known as king tides. In the same study, Wdowinski found there were a total of 16 flood events in Miami Beach from 1998 to 2005. From 2006 to 2013, there were 33.

Although the timing of king tides results from the positions of the Sun, Moon and Earth, rising seas heighten their effect. At extreme high tides, water levels have surged to an inch below the Intracoastal Waterway, says Jennifer Jurado, Broward County’s chief resiliency officer. “Once that’s breached, you’re open to the ocean – the supply of water is endless. The system is really at capacity. These are flood conditions, even with just the high tide and supermoon... You see men in business suits trying to trudge through water.”

Even without floods, the rising water table affects everything. The cities here are built on porous limestone. The water doesn’t just come over seawalls; it seeps up from

beneath the streets. Nearly 90% of the drinking water in south Florida comes from aquifers, and these are finding their fresh water pushed further and further inland as the salt water exerts more and more pressure. Take Hallandale Beach, a small city of just under 40,000 residents. Saltwater already has breached five of the eight freshwater wells that the city draws from, says Vice Mayor Keith London. And around a quarter of Miami-Dade residents use septic tanks. If these don't remain above the water table, the result could be thoroughly unpleasant.

Another issue is beach erosion. Florida's sand may be one of its biggest draws for tourist dollars, but it, too, is vulnerable: though sand never stays put, rising sea levels and worsening storms mean the need to replenish is intensifying. A massive town-by-town project is currently underway; Miami Beach (which, famously, was manmade from the start) just wrapped up its 3,000ft (914m) section, to the tune of \$11.9 million.

Of course, another part of the problem is that south Florida is built on a swamp. "The only reason we live here is we learned how to drain it, we learned how to kill mosquitos, and we created air conditioning," says Jim Murley, chief resilience officer for Miami-Dade County. Residents cut canals to drain inland areas, using the fill to raise the land and build properties. These canals are now open doors for tidal flooding and storm surge. They also cut down mangrove forests and levelled sand dunes – both natural barriers to flooding.

"There is going to need to be a very serious conversation about how we deal with this," says George Vallejo, the mayor of North Miami Beach. "The development that has happened here over the last 40 or 50 years has not been helpful to this situation. We've paved over a lot of the Everglades, we've paved over a lot of greenage.

"We've done a lot of things that, in retrospect, we would have done differently, knowing what we know now."

That's the bad news. But there's good news, says Gassman, whose no-nonsense demeanour and doctorate in marine biology (with a focus on coastal ecosystems) makes her particularly convincing. "That's all if nothing changes. I think that's another thing that the public doesn't necessarily understand: the predictions that they're hearing, time and time again, are if we do nothing. But we're not doing nothing."

That's point one. Point two is that the topography of the area isn't quite what you'd expect. She brings out a map of Fort Lauderdale dotted with squares of purple and orange. Purple means an area is likely to be underwater at 2ft (61cm) of sea level rise; orange means it's possible. A surprisingly small amount of the map is splashed with colour. And the at-risk areas – which are mostly by the bay, not the ocean –

aren't where you might think. "It's not the whole city," she says. "While there are problems in some areas, we'll have to adjust, but these areas are not in places you'd expect – and we'll have time to address some of these issues."

Not every community might be so lucky. Play the inundation game with NOAA's perversely addictive mapping tool in Hollywood, just 10 miles (16km) south of Fort Lauderdale, and you'll find that the same 2ft (61cm) rise could put streets and most properties of an entire square-mile swathe underwater – not insignificant for a city measuring just 30 sq miles (78 sq km). (Hollywood also has its own intervention programme underway, including the installation of 18 flap gates to keep seawater from coming up through the drainage system). Still, it's a good reminder that the problem, as overwhelming as it seems, can be broken down into smaller pieces.

Which is exactly what Gassman and others are trying to do. Touring the city with Gassman is to see it in an entirely new way: not just a city of graceful mansions and pretty canals, but of seawalls that are leaking or too short, fire hydrants that are made of iron ("a fundamental, emergency-based infrastructure that's made out of a material that's potentially corrosive from saltwater"), drains that are overflowing and electrical boxes that need to be raised.

"See, those cars are disappearing from view," she says, pointing to the dip in the road in front of us. We turn onto Isle of Capri Drive. "Look what's happening. Look how far I'm going to go down. This area floods all the time."

Fort Lauderdale is dubbed the Venice of America. That's supposed to be because of its 165 miles (266km) of canals, but recent flooding has made the nickname more on the nose than residents would like.

For both Fort Lauderdale and other communities across south Florida, the main problem is drainage. The systems here were designed to let stormwater drain into the ocean when it rains. Because homes and gardens are higher than the crown of the road, the streets flood first in a storm, by design. Water runs into the storm drain and is piped into the ocean or waterways that lead there.

At least, that's what is supposed to happen. With sea levels now often higher than the exits to the run-off pipes, saltwater is instead running up through the system and into the streets. To make matters worse, when the sea gets even higher, it can breach the seawall, flood people's yards and flow down to the road – where it stays.

Since 2013, Fort Lauderdale has been installing tidal valves to deal with the problem. Each of the one-way valves, which allows stormwater through but not saltwater, looks like a big rubber tube and can be attached inside the storm drains. Gassman pulls one out to show me. “If you stick your hand in there and push a little bit, see how it opens?” I do. “Right there, you were fresh water. Now you’re about to be salt water.” She flips the valve around. I push: sure enough, it’s a no-go.

In some areas, the valves alone have been enough. But there’s a catch: the floodwater still can’t leave if the tide is above the level of the outflow pipes. That happened early on at one of the first places they installed a valve, Gassman says. A king tide came over the tops of the seawalls, flooded the street – and then remained higher than the outfall. “The valve wouldn’t open. So the roads stayed flooded 24/7,” she says. “We have had complaints that the valves aren’t working. But no. The valves are working.”

Despite the limitations of the valves, it doesn’t take an engineer to figure out that raising seawalls would fix flooding that resulted from high sea levels, if not from rain. But until recently, Fort Lauderdale had a height requirement for seawalls that was a maximum, not a minimum – for aesthetic reasons. Though some now do specify a minimum height, enforcement remains difficult. A new seawall runs from \$600 to \$2,000 for a linear foot; adding a 12in (30cm) cap costs about \$60 per foot. For the average homeowner, a seawall measures 75-100ft (23-30m). “How are you going to force everyone to put in money?” asks Gassman.

It turns out you can’t, at least for now. Last year, Fort Lauderdale proposed that everyone should be made to raise their seawalls to a certain height by 2035. Thanks to opposition from the public, the proposal failed. Instead, property owners are required to keep their seawalls in a state of good repair. Someone can be reported to the authorities if their seawall is breached by the tide, but the specific new height requirement only kicks in if someone came to ask for the permit – which is required to do significant repairs, or to build a new wall. And Fort Lauderdale makes an interesting test case: if costs seem prohibitive in this relatively well-off area, it’s not going to work in south Florida’s less affluent communities – some of which also are suffering from similar flooding.

Despite Fort Lauderdale’s best efforts, seawalls here remain a patchwork of heights and states of repair. At Cordova Road, Gassman and I look over the finger isles pointing into the Stranahan River. Across the road from the marina, one house has bright-green grass: it’s new, put down after a flood last spring swamped their property with salt water.

Gassman points to an older house on the corner. Their seawall is about a foot lower than their neighbour's. "That foot of difference allows water to run over their property and flood the road," she says. "That one property, if we could fix that seawall, we could reduce a lot of flooding, right here."

It's not just residents who need to make changes. The city also owns a seawall along this stretch; it, too, was breached recently. Replacing the nearly half-mile stretch could cost up to \$5 million. But getting the funds is just the first challenge. The end of the seawall meets a bridge. If you raise the seawall two more feet, what do you do with that bridge to protect it? And what about the docks that residents are currently allowed to have here, all of which will have to be re-done? "The people that live here want a solution and they want it now," says Gassman. "But there's both a public and a private cost. And changing one piece of infrastructure starts to domino into needing to change all sorts of things."

As well as seawalls, cities are investing in pumps. Many have put pump stations in the worst-hit neighbourhoods. But only Miami Beach has adopted an integrated, major pumping system as part of an aggressive overall defence strategy. Starting in 2013, the programme – which Torriente estimates will cost between \$400 and \$500 million – is multi-pronged. Pump stations have sprouted across Sunset Harbour, an industrial-turned-hip neighbourhood on the barrier island's bay side, and are moving south.

Roads are being raised, too, sometimes by up to 2ft (61 cm), to an elevation which the Southeast Florida Climate Compact's projections put as a likely sea level height around 2065. Seawalls are being raised to a new minimum – something that residents in Miami Beach were more amenable to than in Fort Lauderdale. The city also is requiring that all new properties build their first floor higher.

It's an ambitious agenda. And it's one that's working. Areas where roads have been raised and pumps installed have been much drier. But, as Gassman noted, it's not enough to change one piece of infrastructure without changing everything else. In this case, what happens when you raise a road without raising all of the properties around it? Water can go into the properties.

That's not supposed to happen when the pumps work. But they can fail. Antonio Gallo's Sardinia Enoteca Ristorante is one of a number of businesses that have found their ground floors are now below the current road and sidewalk height. Last year, the pumps failed to kick in after a brief period of rain; the restaurant flooded, with diners stuck inside. When Gallo went to file his insurance claim, it was turned down.

According to the Federal Emergency Management Agency (Fema), which runs a national flood insurance programme for at-risk business and property owners like

Gallo, anything below street level is considered a basement. Until Fema changes their policy, that includes all of the businesses now below the raised streets. Miami Beach is working closely with Fema to get not only Gallo's situation, but the general basement classification, re-assessed.

Miami Beach's efforts are the most aggressive. But resilience also can be built into existing projects. A lot of public infrastructure is built to last for at least 50 or 75 years, and that means planning for what the world will look like then. This is where the Compact's range of scenarios comes in handy. If you're laying down something easily replaceable, like a sidewalk, you could build for one of the more optimistic scenarios. An airport? It's a good idea to go for a higher-risk scenario.

Murley, the chief resilience officer of Miami-Dade County (the county's first), points to a 4,200ft-long (1280m) tunnel that runs from the Port of Miami to highway I395. Opened in 2014, its main objective was to re-route lorries that previously went through downtown Miami. But the tunnel was also given a huge gate that, in a hurricane, drops down to seal it at both ends. "That's an example of resilience. We wouldn't have built that 10 years ago," says Murley. "We would have built the tunnel, but it would have had an open front. We might have had sand bags."

A larger-scale example of built-in resilience is going on at the Central District Wastewater and Treatment Plant on Virginia Key, a barrier island where Biscayne Bay and the ocean meet, just east of downtown Miami. It is one of three wastewater treatment plants run by the largest utility in Florida, which serves 2.3 million of the county's 2.6 million residents. Like the other two, it sits right by the water.

The plant already had a \$500 million project on the go, making changes to comply with new Clean Water Act requirements. But because parts of the facility are expected to last 75 years or more, resilience to higher sea levels and storm surge has been baked into the design. Analysts ran what would be needed in a worst-case scenario: a category five hurricane during a king tide, with maximum rainfall. "What the results told us was that we ought to be building stuff at 17-20ft (5-6m) above sea level on the coast. Our current facilities, by and large, range from 10-15ft (3-4.5m)," says Doug Yoder, deputy director of Miami-Dade's water and sewer department. The new design standards prioritise building at those elevations first for parts of the plants that convey flow – like the electrical wiring and pumps. "At least we won't have raw sewage flooding the streets," says Yoder.

Private developers will need to think about these issues, too. According to the non-partisan research organisation Risky Business, current projections put between \$15

billion and \$23 billion of existing Florida property underwater by 2050. By the end of the century, that leaps to between \$53 and \$208 billion.

But many developers aren't thinking to 2050 or 2100. Their focus is on the time from construction to sale. In a hot real estate market like south Florida, where a lot of investors are foreign or periodic visitors, that timeframe is far shorter – a few years at most.

Until regulations enforce common building standards, few private developers are likely to adopt resilient designs. "I think it's very hard for a developer or builder to do something the code or government doesn't require in their zoning or building code," says **Wayne Pathman, a Miami-based land use and zoning attorney and the chairman of the new City of Miami Sea Level Rise committee.**

One exception is Brickell City Centre, a \$1 billion, 9-acre complex of stores, restaurants, offices, condominiums and hotel in Brickell, a corner of downtown Miami filled with cranes and skyscrapers. Developed by Hong Kong-based Swire Properties, the complex is sleek and airy – and, says Chris Gandolfo, vice president of development for Swire's US operations, resilient. "Starting years ago, Swire was progressive in its thinking on rising tides," he says.

Gandolfo ticks off some of the adaptation strategies that were used: building higher than the current flood plain; flood gates that can seal off the underground car park; an elevated seawall. It also has sustainable features like green roofs, native plants and what the developers have dubbed a "climate ribbon" – a walkway that captures the bay winds to cool the structure and lower energy costs, and works as a cistern to re-use rainwater for irrigation. "We may not make immediate returns," Gandolfo says. "But I think it'll have long-term returns."

All of this puts a catch-22 at the heart of south Florida's development. The state levies no personal or business income taxes and has a low corporate income tax, meaning property taxes provide a major source of revenue. But unless it is managed very carefully, new development brings new challenges.

"Every one of these buildings that goes up expands your vulnerability and magnitude of risk," says Kreeger. "On the flip side, you're not getting help from the state, because the state legislature and governor are in total denial about climate change. So you're bringing in money today which is going to help you. But you're also bringing a bigger problem tomorrow.

Thinking about any of this is a relatively new trend. Although scientists began speaking about sea level rise for several decades, the topic only saw real traction among local governments and businesses a few years ago.

Part of the reason is that the issue was being ignored by so many others. Most officials say that the Compact, signed in 2010, has been a major driver in helping local governments collect the data they need and coordinate together on what to do about it – and it was signed after the realisation that, despite concrete problems that had to be solved today, state, federal and international governments weren't doing what was needed to address them.

The Florida governor is a climate change sceptic and has directed attention away from the issue. Former employees have said they even were told not to utter the phrase “climate change”. Ignoring the issue now appears to pervade the highest levels of US government: the new Environmental Protection Agency (EPA) chief doubts whether carbon dioxide plays a primary role in climate change, while President Trump recently signed an executive order overturning emissions-slashing regulations. Draft versions of the White House budget propose cutting the EPA budget by 31% and employee numbers by 20%, as well as steep cuts to NOAA – including 26% of the funds from its Office of Oceanic and Atmospheric Research and entirely eliminating the Sea Grant programme, whose Florida section brings together 17 different universities to study sea level rise challenges and solutions.

Local governments are forging on, but such circumstances make the challenge even greater. With budgets that run in the tens of millions, not billions, local governments already need to be fiscally creative. Meanwhile, planning depends on up-to-date data – there's no point in raising seawalls if you don't know how high they need to be. And some of the most reliable projection scenarios, as well as sea level rise data, is gathered from NOAA.

Yet the impact from these changes won't stop at party lines. Even President Trump's family isn't immune. Three feet of sea level rise – which the range of predictions put together by Compact estimates is likely to happen within the next 60 years – will flood Trump's Mar-a-Lago estate in Palm Beach.

“It doesn't matter if you're a Democrat or Republican commissioner when a neighbour calls you and tells you that their lawn is flooded,” says Gassman. “The water doesn't care about politics. The water goes where the water goes. And someone who has a flooding problem that's impacting their quality of life or their property values, they don't care what flavour their politician is. What they care about is that the city is

thinking about it, and that they're planning to do something about it."

Some of the communities in south Florida doing the most to adapt to the effects of sea level rise are doing so largely because of public pressure. In 1993, Miami-Dade put together its first plan to reduce carbon emissions. Hardly anyone came out for the committee hearing, Yoder says. Fast-forward to 2015: a hearing on the county's budget was dominated by one resident after another asking why the county wasn't doing more about sea level rise.

So much so, in fact, that the county decided to hire Murley, its first resilience officer. One of his immediate tasks was to look into getting onto the Rockefeller Foundation's 100 Resilient Cities programme. Accepted cities receive funding and tailored guidance on how to make themselves adaptable to future challenges, from high unemployment to earthquakes and sea-level rise.

Greater Miami is just at the start of the process, Murley says. But he's not the only one hoping that the resources made available will help guide the area far into the future. When I try to get in touch with the commissioners or mayor of Sunny Isles, I get a call back from Brian Andrews, a crisis PR consultant. He says sea level rise is something the city is aware of, but that "we're waiting for the county" to gather data and send guidelines for an action plan. "They're getting millions and millions from the Rockefeller Foundation for this," he says. "We're a little city. We couldn't do it on our own."

Despite how awareness of the issue has grown in some communities – particularly those, like Miami Beach and Fort Lauderdale, that have seen the most flooding – it's still common for sea-level rise to get shunted to the end of the list of priorities. "As an elected official, when I go knock on doors, resiliency and sea level rise is never discussed," says Esteban Bovo, chair of the Miami-Dade County Commission. "It's never talked about. It's crime, how much we're going to invest in police, how much we're going to invest in traffic, how much we're going to invest in public safety, libraries – those are the topics of conversation."

Later, I find myself playing with the NOAA sea-level tool again. I zoom in on Sunny Isles. At 1ft, the low-lying mangrove swamps of the Oleta River State Park, just over the water, are submerged and the wooded backyard of the Intracoastal Yacht Club disappears. At 2ft, the St Tropez Condominiums and the newly-built Town Center Park are underwater, as are many shops around 172nd Street. At 3ft, things start to get serious. Blue blots out the entire shopping plaza and the Epicure Market. At 4ft,

the entire west side of Sunny Isles is uninhabitable. At 6ft, it's gone. Only the spine near the beach – where my father lives – remains.

It's easy to look at Compact's range of estimates and think that, since a 3ft or 4ft rise may remain fairly far off, everything will be fine for a few more generations. But it's not. With public infrastructure – from fresh water to flushing toilets to roads – woven between communities, if just one area gets affected, others may suffer. Meanwhile, resilience is only one piece. As shown by the Compact chart's steep orange line, if emissions continue to rise, adaptation will become increasingly difficult – if not impossible. And unlike raising seawalls or installing tidal valves, that, of course, can't be controlled by a community or region alone. "Climate change mitigation to reduce greenhouse gases is a global issue and has to be dealt with globally," says Gassman. "Adaptation to the inevitable effects of climate change is a local issue."

Later, peering out the window as my plane takes off over Miami, I no longer see the dense green squares of the city's western edge, the sharp skyscrapers downtown and the surprisingly slender line of barrier islands. Instead, I see what might be lost. From here, the ocean looks vast.

But as the plane climbs, I remind myself that human innovation was enough to drain the swamp and make Florida what it is today. It was great enough to get me here, 15,000ft in the air. And it just might be enough to save what I see below.

....