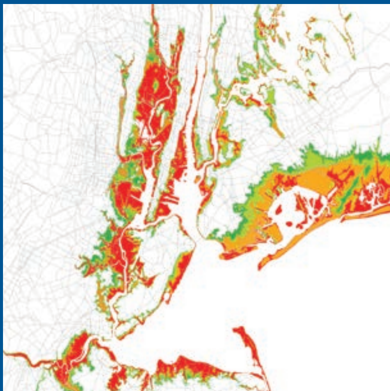
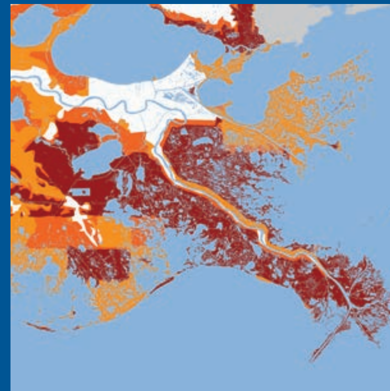
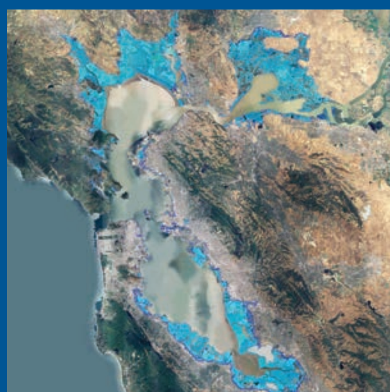
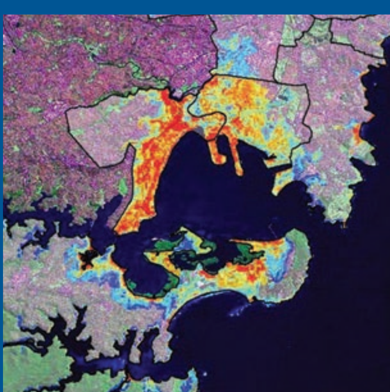
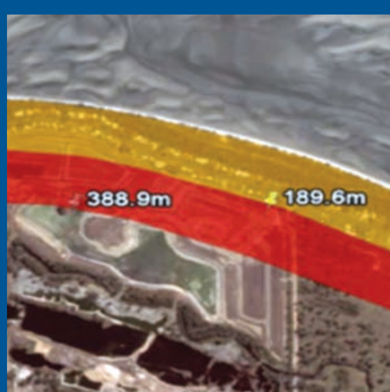


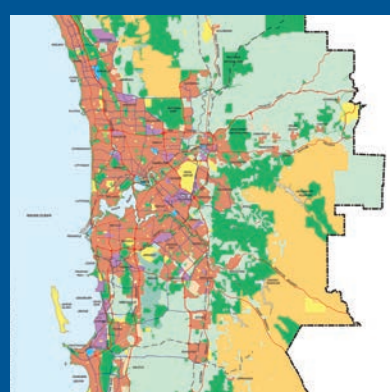


Resilient Coastal City Regions


Planning for Climate Change in the United States and Australia



Edited by **Edward J. Blakely** and **Armando Carbonell**

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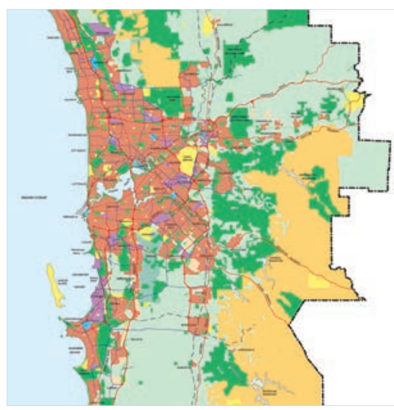

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Sea level maps:
The maps of the United States, Australia, and the nine coastal regions were prepared by Jeremy Weiss, senior research specialist, and Jonathan T. Overpeck, professor, Department of Geosciences, University of Arizona, Tucson. www.geo.arizona.edu/dgesl/

An explanation of how Weiss and Overpeck developed the elevation datasets of low-lying coastal areas is available in: J. L. Weiss, J. T. Overpeck, and B. Strauss. 2011. Implications of recent sea level rise science for low-elevation areas in coastal cities of the conterminous U.S.A. *Climatic Change* 105: 635–645.

On each map, the dark blue overlay areas indicate low-lying coastal areas of $\leq$ 1 meter elevation vulnerable to future sea level rise.

Cover images are details of figures and photographs as follows: top (left to right): figures 1.4, 2.5b, and 3.2; middle: aqueduct, Central Valley, CA (chapter 4), figure 5.3, and Yarra River pollution plume (chapter 6); bottom: figures 7.5, 8.7, and 9.2

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Figure 6.1 Melbourne

Source: Weiss and Overpeck, University of Arizona.

dark blue overlay areas = low-lying coastal areas of ≤ 1 meter elevation vulnerable to future sea level rise

Chapter 6

Melbourne

Peter M. J. Fisher

Melbourne, the state capital of Victoria in southeastern Australia, is a large seaboard city (figure 6.1). Prior to the rise of global warming concerns, decadal climate variation across the region had been viewed as a gradual, creeping process—not entirely human-friendly, but unlikely to make the state a difficult place to live. If considered at all, anthropogenic climate change was not regarded as likely to occur. By the mid-2000s, however, some people became concerned about a 12-year drought arising from a prolonged El Niño event and punctuated from time to time by a weak La Niña event that resulted in diminished dam levels, severe water restrictions, and dustbowl conditions. Then on 7 February 2009, later named Black Saturday, killer firestorms to the east and north of Melbourne incinerated 173 people and a million animals. The fires burned 450,000 hectares (ha), destroyed more than 3,500 buildings, injured 414 people, and displaced 7,562 others. Once temperatures and winds reached extreme proportions, the dryness already in effect was an invitation to cataclysmic fire.

Shaken by the failure of fire plans to prevent this tragedy, the Labor government then in power established the Victorian Bushfires Royal Commission (2009a) and declared "unconditional support for residents wishing to rebuild their homes and towns" (*Weekly Times* 2009, 1), regardless of whether those sites were safe—the very matter the commission was charged to investigate. The government seemed neither to recognize nor address the distinct possibility that climate change is altering the vegetation as a result of frequent devastating fires in settings where there has been a considerable influx of "tree change" residents. James Hansen and his colleagues predict that there will be even more extreme summer heat events, which indicates that very hot fires are also likely and will only hasten that vegetative transformation.

> The "climate dice" describing the chance of an unusually warm or cool season, relative to the climatology of 1951–1980, have progressively become more "loaded" during the past 30 years, coincident with increased global warming. The most important change of the climate dice is probably the appearance of extreme hot summer anomalies, with mean temperature at least three standard deviations greater than climatology, over about 10 percent of land area in recent years. These extreme

> temperatures were practically absent in the period of climatology, covering only a few tenths of one percent of the land area. Therefore we can say with a high degree of confidence that events such as the extreme summer heat in the Moscow region in 2010 and Texas in 2011 were a consequence of global warming. (Hansen, Sato, and Reudy 2011, 1)

Meanwhile, the government's response to a metropolitan water deficit several years earlier was to build a desalination plant and interbasin pipelines to deal with the decline in rainfall that began in 1998. Despite an enhanced dependency on electricity to carry out these measures, policies built on the efficiencies of integrating water making and power generation were not pursued.

Beginning in 2010, the El Niño event was replaced by a strengthening La Niña that resulted in high rainfall, flash flooding, and steadily rising metropolitan dam levels. Later that year the state Labor government was defeated by the coalition opposition (the Liberal and National Parties), which had promised to abandon the desalination plant, but eventually claimed they were unable to do so because of contractual obligations (Davidson 2011).

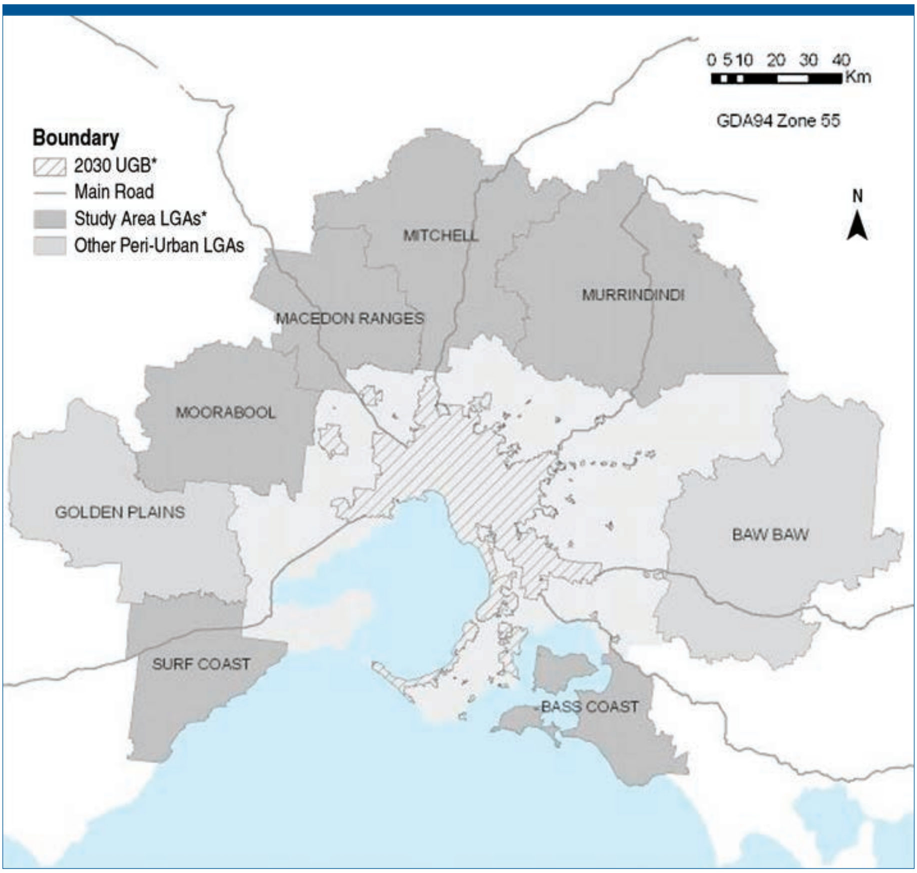
Consequently, this chapter focuses on these two climatic eras—the 12-year drought followed by a period of record-breaking rainfall—that reflect a wild swing in weather conditions considered characteristic of advancing climate change. Victoria's experience at the front lines of that change may offer lessons of value to other places with similar weather patterns, such as Southern California.

The Geopolitical Dimension

Despite being home to fewer than half the inhabitants of London, the Melbourne metropolis covers a larger land area (figure 6.2). Its population stands at 4.1 million and is increasing at an annual rate of 2 percent—adding more than 200 people a day or almost 1,500 a week. In 2010, for the ninth consecutive year, Melbourne experienced the highest growth among the capital cities in Australia. Current projections by the Australian Bureau of Statistics estimate the population will swell to between 6.5 and 7.5 million by 2051 (Colebatch 2011).

The metropolis dates from 1835, when an area 10 kilometers (km) upstream from Port Phillip Bay on the Yarra River adjoining a cascade of freshwater of drinking quality above and navigable brackish water below, was chosen by pastoralists from the Launceston-based Port Phillip Association as a good place to found a village. Development was explosive. In 1851 a gold rush centered on Bendigo 150 km north and Ballarat 100 km northwest led to a large influx of diggers, including many who came from the earlier gold rush in California. By 1860, 22 main roads radiated out of Melbourne, establishing much of today's arterial road network. This gold-driven boom continued until a depression occurred in 1890. By then, however, "Marvelous Melbourne," as it had become known, had a population of 490,000, making it Australia's largest city.

Figure 6.2 Peri-Urban Municipalities Surrounding Melbourne
Source: Buxton et al. (2011).



** UGB = urban growth boundary; LGAs = local government authorities.*

In the lead-up to the bust in the 1890s, extensive residential subdivisions were built along new railway lines in the eastern half of the city, where the terrain and climate made living conditions more hospitable than areas on the western flank. Regular train services helped to consolidate outlying market towns as housing pushed into intervening spaces and land was cleared for farming, orchards, and market gardens. The 1920s saw the rapid spread of motor vehicles, but continued growth was stunted by the Great Depression and World War II.

By the end of the 1940s Melbourne's population had reached 1.3 million residents. Car ownership, the establishment of wide, paved highways, higher disposable incomes, and shorter working weeks acted to bring formerly isolated areas within easy reach and made them ripe for housing. In 1971 the Melbourne and Metropolitan Board of Works—the authority charged with metropolitan planning—adopted a green-wedge-and-corridor development format for city growth, a pattern that largely persists, but has come under pressure from successive governments to rezone incremental sections of green acres to

The ruins of a house amid choking smoke in Marysville 24 hours after the Black Saturday conflagration, during which 38 people perished in the town while others huddled on a sports oval until forced to flee eastward to Alexandra in a police-escorted convoy of cars.
Photograph: © Keith Pakenham.

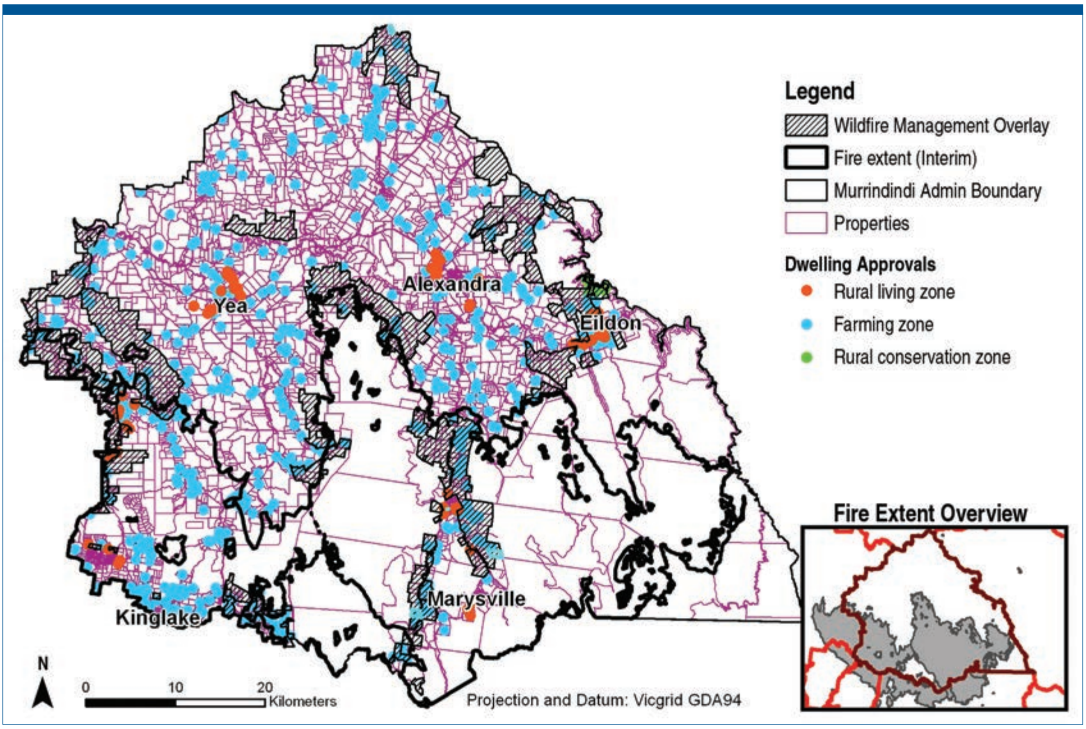
accommodate Melbourne's population growth. Over the years, administration of statutory planning schemes to implement the green-wedge-and-corridor provisions has been shared among local councils and state agencies, depending on which issues the Victorian government considered to be of state significance. In a new twist the coalition government has requested green wedge councils to nominate land for potential inclusion within a revised boundary to overcome "anomalies." Of the 11 councils, 8 have rejected any changes to Melbourne's long-standing green wedges or failed to make submissions by the deadline (Whitelaw 2011).

In 2010, almost half of the city's population lived in suburbs lying more than 20 km from the central business district. An estimated 600,000 people now reside in the high-risk, fire-prone, peri-urban areas, and many of them commute to jobs within the built-out area (Buxton et al. 2011).

The royal commission established to inquire into the Black Saturday fires was told by six different planning and environment experts that rebuilding homes in places such as the burnt-out town of Marysville would be inadvisable. They added that the risk was so great in some parts of Victoria that residential development there should be prohibited, and this ban should also cover new development and new subdivisions in existing areas (Buxton et al. 2011; Gray

Figure 6.3 **New Dwelling Approvals in Murrindindi Shire, 1997–2007**

Source: Buxton et al. (2011).



2010a). The experts also called on the government to consider buying back some privately owned land in areas at risk for fires. Nevertheless, numerous new building approvals have been and continue to be granted in the heart of the zone ravaged by the Murrindindi firestorm (figure 6.3).

Regional Climate Change Issues

In the years prior to 2006, the policy focus related to climate change in Victoria and elsewhere in Australia was limited to mitigation—in other words, reducing greenhouse gas (GHG) emissions. Recognizing, however, that change in the earth's geophysical system is inevitable, as witnessed by an increasing number of extreme weather events in Europe and other global regions, this response gradually expanded to include adaptation.

A report prepared for the Port Phillip City Council (City of Port Phillip 2007) was one of the first attempts to inform Australian local governments of the role they could play in limiting climate change and natural hazard impacts on private and public assets. Another study of Melbourne's Western Port region undertook a similar assessment (Kinrade et al. 2008). Other specialist studies, including those prepared by the Commonwealth Scientific and Industrial Research Organisation, Australia's national science agency (CSIRO 2005), examined the water, sewerage, and drainage systems of Melbourne, and a

Hard surfaces cover the alley of a new development in the Melbourne suburb of Brunswick.
Photograph: © Peter M. J. Fisher.

report by Victoria's Department of Sustainability and Environment (DSE 2006) investigated the vulnerability of infrastructure.

During three consecutive days of 43–44ºC temperatures in January 2009, overuse of domestic air conditioners produced power outages with repercussions including disabling the rail network. Rails also buckled on lines not equipped with concrete sleeper ties (NCCARF 2010). The lessons were clear: emergency response systems needed to be improved, design changes made, and some equipment re-engineered to cope with temperature extremes. Rail authorities subsequently undertook some engineering adjustments (Fisher 2009). Extreme heat further affected electricity supplies when a transmission line transformer failed, and the Black Saturday fires a few weeks later threatened the main transmission line to Melbourne and advanced perilously close to the Loy Yang power station and an adjoining coal mine.

Strong population growth in the region's coastal areas has exposed increasing numbers of residents to the threats of storm surge and sea level rise. CSIRO has estimated that between 27,600 and 44,600 homes in the state could be at risk of inundation from a 1.1-meter sea level rise and tidal surge associated with a 1-in-100-year storm. In fact, their research shows that Victoria has the third-highest number of residential buildings at risk of inundation in Australia, at a replacement value of $6.5–$10.3 billion* (Department of Climate Change 2009). Of these homes, 70 percent are situated in the Melbourne area, notably the municipalities of Kingston, Hobsons Bay, Greater Geelong, Wellington, and Port Phillip. The Climate Commission (2011) has noted that in Melbourne (as well as Sydney), a sea level rise of 0.5 meter leads to very large increases in the incidence of extreme events by factors of 1,000—or 10,000 for some locations.

Some developments or redevelopments close to the sea still had slipped through the planning net, in spite of a sea level rise identified by the Western Port Alliance study (Kinrade et al. 2008) and a new strategy of the Victorian Coastal Council (2008). At least one arm of state government, the Victorian Civil and Administrative Tribunal (VCAT), seemed prepared to grapple with some of the tough implications of climate change in 2008, when it overturned South Gippsland Shire's approval of a six-dwelling planning permit application on the Toora coast. VCAT (2008) conceded that planning for climate change was still in an evolutionary phase and the risk from storm severity would make the proposed developments unacceptable. However, the new coalition government's decision to relieve a council in the state's far west of its controls over development within a zone vulnerable to a 0.8-meter sea level rise suggests a loosening of this approach (Dowling 2011a; 2011b).

Built environments with little space devoted to cooling and the wind-modulating effect of trees continue to emerge in Melbourne although the central city recently has developed a strategy to maintain and enhance trees on its streets and public lands (City of Melbourne 2011). A profusion of heat-absorbing masonry and other hard surfaces that threaten to overload drainage systems when downpours occur has been the norm.

Following a climate change summit in May 2008, a Premier's Climate Change Reference Group was established "to provide expert, independent advice on a range of climate change issues" (Victorian Government Department of Premier and Cabinet 2009, 15). The group focused on mitigation and strongly advocated early action by Victoria in a series of detailed recommendations. Its chairman, Intergovernmental Panel on Climate Change climatologist Professor David Karoly (2009b, 1), made this observation after the group had finished its work.

> The Victorian Government's ambitious green paper on climate change includes discussion of many important actions to respond to climate change through both adaptation and emissions reduction. But the Government appears unwilling or unable to accept that an urgent whole-of-government approach is needed, with limits on population growth, a strategy to phase out brown coal power stations, huge investment in

* Unless otherwise noted, dollar amounts cited in this chapter refer to Australian currency.

low-carbon energy sources and public transport, and regulations requiring dramatic improvement in energy efficiency.

In 2009 Victoria's government established a partnership with Melbourne, Monash, La Trobe, and RMIT Universities for the Victorian Centre for Climate Change Adaptation Research (VCCCAR). Another development that year was the creation of the royal commission following the Black Saturday fires, which were attributed at least in part to anthropocentric climate change, as was the decline in water storage levels (Karoly 2009a). The new coalition government has since adopted its predecessor's policy of reducing emissions by 20 percent by 2020, but it has abandoned plans to shut down the high-emission Hazelwood power station and permits commercial exploration for brown coal to proceed in the nearby region.

Natural and Man-Made Conditions

A Unique Intersection of Climate and Vegetation

Australia separated from Antarctica 45 million years ago, but the new oceanic circulation opened by the rift affected world climates (White 1994). Although it was no longer contiguous, Antarctica cast a long climatic shadow from the deepest latitudes over its receding neighbor. Even today, research has demonstrated a strong correlation between increased snowfall at Law Dome in East Antarctica and decreased rainfall in the southwestern parts of Australia, and vice versa (AAP 2010; Ommen and Morgan 2010). This derives from two atmospheric moisture corridors: one that blows dry air from the Southern Ocean over southwestern Australia while the other shifts moist air southward to Antarctica. A pressure system that lies between the two continents may be the lynchpin for this atmospheric seesaw.

The resultant drying led to a contraction of the wet Gondwanan forests and their eventual replacement by arid-adapted vegetation, including the progenitor of the gum tree or eucalyptus. Frequent fire was inevitable in this new landscape, and the gum evolved to eliminate competitors in the Gondwanan rainforest by secreting highly flammable oils that encourage ignition, orienting its leaves to reflect sunlight downwards to dry out the understory, and using a shedding bark to start fire ahead of a main blaze. To survive such maelstroms, the trees are able to regenerate from epidermal buds or seed rains, as in the cases of *Eucalyptus regnans* (mountain ash) and *Eucalyptus delegatensis* (alpine ash), both of which are killed by fire.

This is the problematic landscape into which increasing numbers of people have cast themselves since European settlement of Australia started in 1788. The peril to lives and livelihoods was forever present, as demonstrated by the blazes of Black Thursday in 1851, when 25 percent of Victoria is believed to have gone up in flames. However, fewer people lived in the state at that time.

Anthropocentric Climate Change

In February 2010, just one year after Black Saturday, epidermal buds of eucalyptus have regenerated in Toolangi Forest. *Photograph: © Janet M. Bridgart.*

Victoria's climate has changed radically over the last century, with a pronounced warming since the decade of the 1950s. Research shows one indicator of this trend: indigenous butterflies are emerging from their cocoons 10 days earlier than they did 65 years ago, which correlates with a 1ºC warming (Phillips 2010).

Higher levels of carbon dioxide (CO_2) as well as rain-bearing low pressure systems tracking further south are viewed as playing a key role in the warming over recent decades. This contemporary climate change is increasing fire risk for a growing population. Future fires could penetrate Melbourne's generously treed outer suburbs to the east and northeast, causing a death toll that could be counted in the tens of thousands rather than the hundreds lost on Black Saturday. The ferocity and heat of the crescent of fire on that day summons a parallel with the virtually uncontrollable blazes of Southern California in the path of the Santa Ana winds or Mediterranean countries affected by the siroccos from North Africa.

A combination of a marked decline in rainfall resulting in tinder-dry conditions, a location at the end of a 2,000-km northwesterly wind trajectory over the hot, baking deserts of Central Australia, and an abundant tree species that deliberately promotes fire, thrusts Victoria into the front line of climate change. Flame-gas heights during the Murrindindi fire on Black Saturday, for example, exceeded 100 meters and burned at temperatures of 1000ºC or greater. This fire triggered a thunderstorm with lightning over the Mt. Riddell blaze near Healesville, which suggests it created its own microclimate on a day of record low humidity. By contrast, the impact of the drought and rising aridity had been creeping and was far less traumatic. Yet the two phenomena were closely related: the greater the desiccation, the higher the risk of fire and its heat and ferocity.

Grasping the Intricacies of Melbourne's Climate

South Eastern Australia's weather derives from a complex interplay of four main climate drivers: El Niño–Southern Oscillation (EN–SO), the Indian Ocean Dipole (IOD), the Southern Annular Mode (SAM), and the Subtropical Ridge. El Niño events arise from sea surface temperatures in the central and eastern tropi-

At Lake Mountain, the aftermath of the Murrindindi fire revealed pyrolized and gasified leaves, a result of extreme radiant heat.
Photograph: © Janet M. Bridgart.

cal Pacific Ocean that are warmer than normal and linked with an anomalous atmospheric circulation called the Southern Oscillation (Mullen et al. 2010).

Both El Niño and La Niña events normally last for about a year, but they can be shorter or much longer. There have been four recent La Niña events: 1998–2001 (moderate), 2007–2008 (weak to moderate), 2008–2009 (weak to moderate), and 2010–2011 (very strong; figure 6.4). In Victoria, El Niño events typically result in reduced rainfall from March to November.

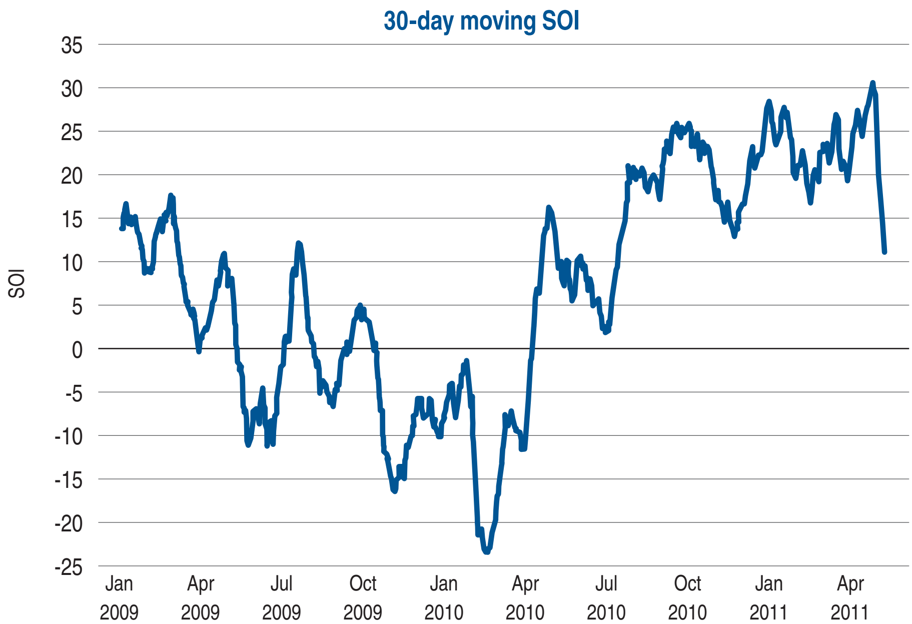
The IOD, a relatively recent discovery, arises from a difference in sea surface temperatures near Africa compared to those near Sumatra and Northern Australia. A positive phase of the IOD is associated with decreased rainfall over southeastern Australia from June to November.

Roger Jones (2009) believes that climate change is implicated in blocking highs and SAM intensification, and perhaps the IOD as well. Natural climate variability also may be interacting with these changes. He records that from the period between 1996 and 1998 until 2010 a statistically significant shift occurred in mean annual rainfall, mean annual stream flow, and mean daily maximum temperature. The annual rainfall decreased by 21 percent, with the largest decreases in spring (23) and autumn (29), next in winter (18), and least in summer (13). For stream flow, the annual decrease was 39 percent and the largest seasonal decrease has been in autumn (46), with the least in spring (35). Maximum daily temperature rose annually by 1°C, increasing 1.2°C in spring and summer, 0.7°C in autumn, and 0.8°C in winter.

Interestingly, in southeastern Australia La Niña events similar to those from 2000 to 2009 had not resulted in a resumption of plentiful levels of winter and spring rain, partly because the IOD generally has been in a positive phase during the events. As a result, there was no letup in dryness from late 1996 until the start of 2010. In its negative phase, the IOD brings warm water to the north coast of Australia, which results in increased evaporation into the atmosphere and rain-bearing air sweeping over the continent. It remained generally positive for three years, from 2006 to 2009, even though such a three-year sequence is rare. The major decrease was in autumn rainfall, thought to be due to the more intense central air pressure of the subtropical ridge (Timbal 2010).

Figure 6.4 **The Southern Oscillation Index (SOI) Demonstrates the Strength and Duration of La Niña Events**

Source: National Climate Centre, © Commonwealth of Australia (2011).



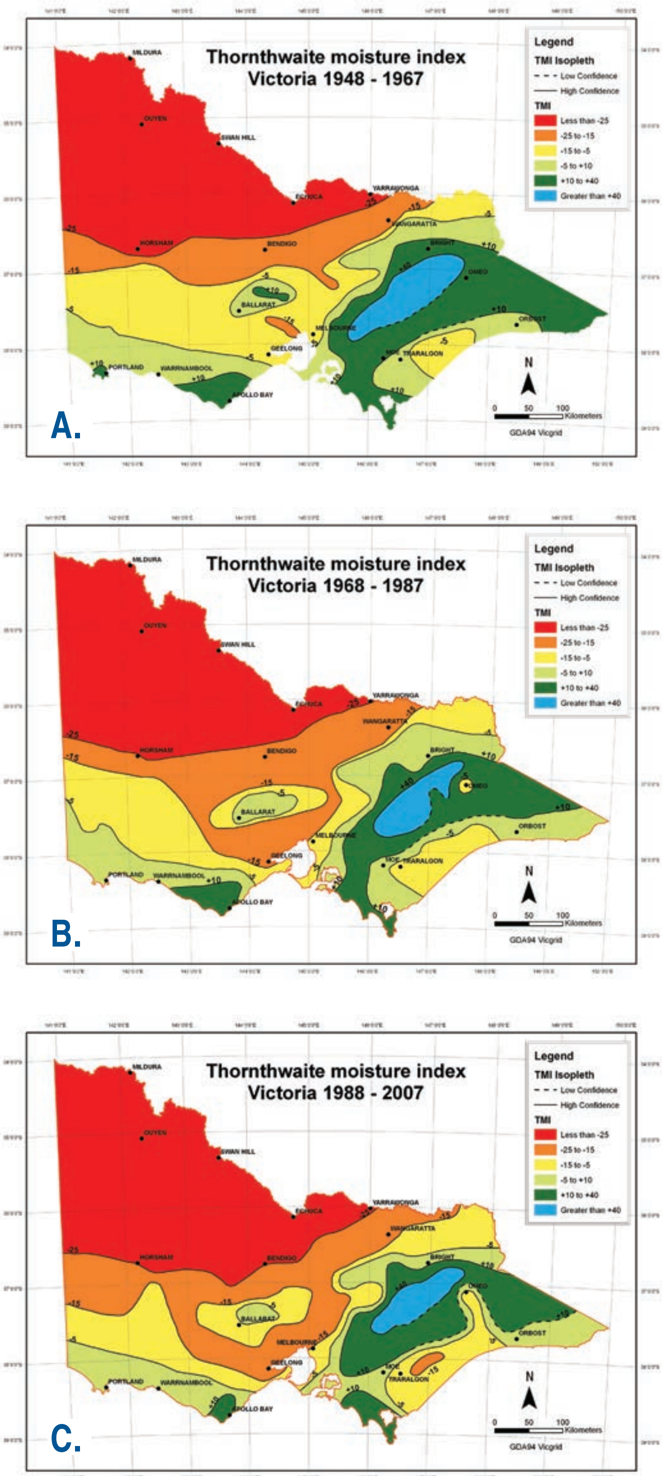
With a La Niña event well established in the Pacific Ocean, however, 2010 saw a wetter weather pattern emerge, and it grew to major proportions by early 2011. Among the ramifications was a "tropical link," with one particular cyclone moving inland from the Coral Sea then tracking south as an intense low pressure system. This produced subtropical conditions and culminated in vast flash flooding in Melbourne and extensive flooding elsewhere in the state's northwestern areas during January and February. Despite these developments, the long-term conditions that led to decreased rainfall since 1996 are still believed to be operative (Roger Jones, personal communication, 2010).

Increasing Aridity and Bushfires: Desiccation, Heat, and Destruction

The extended period of drought in Victoria ended with the "big wet" of 2010–2011, but the drought had exacerbated what was already a steady decline in soil moisture from as early as 1968, as determined by the Thornthwaite moisture index (figure 6.5). Apart from the soils in its eastern suburbs, the moisture content of Melbourne's soils equaled that of the drier Bendigo region (just over the Great Dividing Range to the north) earlier in the study period from 1948 to 2007. In other words, for years the metropolis and its peri-urban areas had been succumbing to desiccation and the consequent elevation of fire risk.

Figure 6.5 Soil Moisture in Victoria, 1948–2007 (Thornthwaite moisture index)

Source: Lopes and Osman (2010).



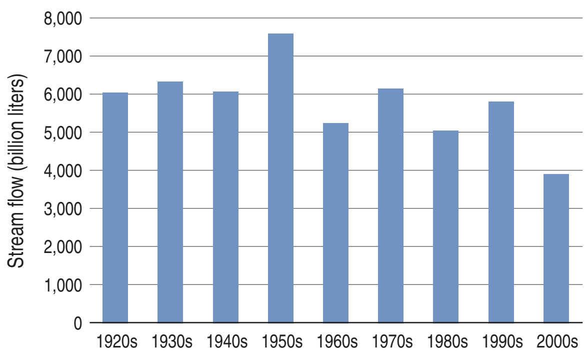
In general, until there is enough rain to dampen the whole system, rainfall refills the soil profile and trickles into groundwater with less run-off. In turn, stream flows are reduced significantly. Thus, a 10 percent decline in rainfall on Melbourne's drinking water catchments over the period of the drought resulted in a 30 percent reduction in inward stream flow (figure 6.6). Dam levels dropped from nearly full in 1996 to barely one-quarter full in 2009, with a steep reduction in the amount of water that flowed into the city's major reservoirs. Increased rainfall in 2010–2011 caused the overall dam levels to rise to two-thirds capacity, while the major Thomson Dam reached 50 percent capacity.

These variables of soil moisture and rainfall also have a bearing on low levels of relative humidity. The dry heat typical of summers in Victoria brings about humidity levels that hover around 10 to 20 percent. The low humidity is exacerbated by wind changes accompanying the passage of cold fronts, which increase the dehydrating effects of high winds in the form of hot northerlies that follow. These have become more intense in recent years.

In the 1960s the interplay of weather conditions was integrated into the McArthur Forest Fire Danger Index (FFDI or simply FDI), an empirical indicator of high and extreme fire danger and the relative difficulty of putting out blazes (Karoly 2009a). The FFDI is used for rating fire danger culminating in public warnings for high (FFDI 12–25); very high (25–50); and extreme (>50). An extreme rating is accompanied by a total ban on fires. A report prepared for the Bushfire Cooperative Research Centre indicated that values may substantially exceed 50 (Lucas et al. 2007, 2).

Figure 6.6 Changes in Stream Flow in Melbourne's Water Catchments

Source: Melbourne Water.



The annual cumulative FFDI values mask much larger changes in the number of days with significant fire risk. The daily fire danger rating is "very high" for FFDI greater than 25 and "extreme" when FFDI exceeds 50. Two new ratings have been defined for this report: "very extreme" when FFDI exceeds 75 and "catastrophic" when FFDI exceeds 100. The number of "very high" fire danger days generally increases 2–13 percent by 2020 for the low scenarios and 10–30 percent for the high scenarios. By 2050, the range is much broader, generally 5–23 percent for the low scenarios and 20–100 percent for the high scenarios. The number of "extreme" fire danger days generally increases 5–25 percent by 2020 for the low scenarios and 15–65 percent for the high scenarios. By 2050, the increases are generally 10–50 percent for the low scenarios and 100–300 percent for the high scenarios.

In the wake of the Black Saturday fires, two additional warnings, extreme (FFDI 75) and catastrophic code red (>100), have been adopted across the continent. The official advice for code red is, "if you live in a bushfire prone area the safest option is to leave the night before, or early in the morning" (Gray 2010b, 7).

Heat, Fire, and Water: Challenges and Experiences Under El Niño Conditions

Soaring Temperatures and Firestorms

Recent incidents. On Saturday, 7 February 2009, temperature records were rewritten across the state of Victoria. The hottest place was Hopetoun in the northwest, with a new statewide benchmark of 48.8°C. In Melbourne, the maximum was 46.4°C, more than three degrees hotter than on Ash Wednesday in 1983, the day holding the previous February record. The FFDI reached

Roadside fire alert signs such as this one at Trafalgar, Victoria, show the six risk categories. As a result of Black Saturday, these signs now dot rural Australia.
Photograph: © Peter M. J. Fisher.

unprecedented levels, ranging from 120 to more than 200, and relative humidity plunged down to 6 percent following a week of record temperatures in late January, during which 374 infirm and elderly citizens died from heat exposure.

But the scene had been set well before 7 February dawned. A day earlier, V-Line, the regional passenger train provider, warned of a possible cessation of service on the Gippsland line due to the prospect that the Bunyip State Park fire could flare up and cut off the tracks, which subsequently occurred. Services were also cut on the Seymour and Warrnambool lines. As many as 400 fires were recorded around the region.

A blustery, cool change later in the day swung the wind direction 90 degrees, converting initially long, narrow fire fronts into wide ones that moved in a northeasterly direction, with spot fires flaming up as far as 20 km ahead.

The main blazes were the Kinglake-Murrindindi, Bunyip, Churchill, Bendigo-Redesdale, and Beechworth complexes. The first two were in the greater metropolitan area while the third threatened the state power supply. The fourth penetrated the western suburbs of Bendigo, a provincial city of 100,000 people, and burned to within 2 km of the central business district.

This ominous occurrence brought the Kinglake-Murrindindi blaze precariously close to the heavily populated, leafy suburbs of outer Melbourne—Eltham, Greensborough, St. Helena, and Warrandyte (Bachelard 2009). The Kinglake-Murrindindi fire complex, which resulted from the merging of sep-

These ruins of a house and car in the aftermath of Black Saturday were typical of the devastation. One can recognize the random selectivity of the fire's damage, however, by contrasting the relatively untouched oak tree to the left with the scorched, leafless one on the right.
Photograph: © David Bethell.

arate blazes after a wind change in the late afternoon, killed 159 people and destroyed 1,800 homes and 330,000 ha of land.

After the wind change, the fire turned toward the town of Marysville in the evening, where 38 lives were lost. Temperatures were so high (up to 1,200ºC) that burned vehicles' engine blocks were melted, and forensic teams had great difficulty identifying many victims. It was later determined that 173 people had perished across the state. The destruction of convention facilities, bed and breakfast inns, and other visitor attractions has severely limited the economic recovery of Marysville since the fires.

Black Saturday also showed that Melbourne's surface water supply was in jeopardy, not only from growing aridity but also from serious contamination of its catchments due to burnt vegetation. The Kinglake-Murrindindi Complex South fire broke into the O'Shannassy River and Armstrong Creek water catchments on Tuesday, 10 February. Heavy rainfall in its wake would have caused mud, ash, soil, and rocks to be washed into the dams, something that occurred after the January 2003 fires in Canberra.

Policy responses. Victoria's premier, John Brumby, visited the ravaged towns on 9 February 2009, when he announced that a royal commission would examine "all aspects of the government's bushfire strategy including whether climate change contributed to the severity of the fires" (Australian Broadcasting Corporation 2009). Touring Marysville, Buxton, and Kinglake with Brumby on 17 February 2009, Kevin Rudd, then Australia's prime minister, declared that communities wiped out by Victoria's bushfires would be rebuilt "brick by brick" (Nicholson and Rood 2009). Edward Blakely (2009, 11) publicly cautioned against such assertions, observing:

> It makes little sense to build back into trouble. But in too many instances the desire to build back soon overwhelms the need to build new safer and smarter systems that can withstand foreseeable hazards like climate change. In New Orleans we are learning from the Dutch how to build a city less dependent on levees to secure a better and more sustainable city. Victorians can and should learn from Canberra's disaster as well as identify best practices globally as it rebuilds its communities.

On 10 February, the national and state governments together established the Victorian Bushfire Reconstruction and Recovery Authority to oversee and coordinate a recovery and rebuilding program. Its priority was to "help regions, towns and individuals to rebuild and recover in a way that is safe, timely, efficient, cost effective and respectful of those different needs" (FRU 2011). This authority was also charged with distributing a large amount of money, food, and household items collected for bushfire victims.

Meanwhile, weather predictions, including very strong northerly winds followed by a blustery change, caused the people of Victoria to brace for another maelstrom on 3 March. The police department sent text messages to nearly 3 million cell phones, reportedly as a test for a new telephone-warning system. Fortunately, it was a false alarm, although some adverse comments arose, charging the department of "crying wolf."

The royal commission began its hearings in April 2009. Jack Rush, the counsel assisting the commissioners, took early aim at the alert the public had received before the Black Saturday fire, stating: "The only warning on the day was for an extreme fire danger. Such general warnings [are] not a trigger to go early. . . . Australia allowed people to make a choice about whether to stay or go rather than requiring them to evacuate. In other countries with a high wildfire risk, evacuation is still seen as the safest emergency approach" (*The Age* 2009, 1).

Under prior government-endorsed fire plans, the *stay-and-defend-or-go* (abbreviated to *stay or go*) policy assumed it was possible for a well-prepared resident to defend a property. The Australian design standard AS 3959-2009 (Construction of Buildings in Bushfire Prone Areas), in particular, holds that properties can be constructed "that will give a measure of protection to the building occupants [until the fires passes] and to the building itself." Clearly, many of the buildings destroyed on Black Saturday did not meet this standard, which was developed for conditions prevailing during

Table 6.1 Comparison of Actual Conditions with Design Assumptions of the Australian Standard (AS) 3959–2009

Source: Grundy (2009).

Parameter/Case	AS 3959–2009	Australian Capital Territory 18 January 2003	Victoria 7 February 2009
Air temperature	35°C	37.4°C (12:42 p.m.)	46.4°C Melbourne
Wind	34 km per hour[1]	78 km per hour (gust)[2]	>100 km per hour
Relative humidity	25 percent	4 percent (4:30 p.m.)	6 percent
Rate of fire spread	3 km per hour	unknown	8 km per hour

Notes:

1. Only used for calculating rate of fire spread in scrub or scrubland, not in forest or woodland.

2. A 14-km high cumuliform plume of dry, unstable air above the ACT fire caused gusts exceeding 100 km per hour and storm damage before and during the firestorm. Gusts in the Kinglake and Marysville firestorms in Victoria are believed to have been even stronger.

the Black Friday fires of 1939. The contrast with actual conditions in Victoria is stark (table 6.1).

It appears that AS 3959-2009 assumed an FFDI of 100, but in Victoria on Black Saturday it ranged from 120 to above 200. Whereas it is not uncommon for impact variables to exceed design standards with earthquakes, for example, this analysis indicates that the design standard may need to be reviewed. The royal commission recommended that people should be encouraged to use shelters, the government should cease telling people that houses are safe, and evacuation should be the primary option (Victorian Bushfires Royal Commission 2009a). Even if the former prevails, Grundy (2009, 3) points out that:

> the areas not burnt this time will be more at risk from bushfires next summer than the areas which were burnt. Although the burnt areas will be rebuilt to a more robust standard of fire resistant structures they will remain vulnerable with even the most fire resistant structure being at risk of destruction, as was demonstrated on Black Saturday. Within the burnt area there are many surviving houses, including timber clad houses, which also remain vulnerable. Accordingly, a risk reduction plan needs to be developed for the unburnt areas where it is likely that only minor modifications to buildings at risk will prove economically and socially acceptable. The same plan should apply to areas recently burnt.

The places not affected on Black Saturday should be given as much concern as the devastated areas. Whereas only 38,000 people permanently reside in those towns that escaped the fire, hundreds of thousands visit or vacation there in the summer months. Melbourne University bushfire researcher Kevin Tolhurst has articulated the perils they could face.

> Fourteen towns not burned out on Black Saturday—from Lorne and Aireys Inlet to the west of Melbourne, through Macedon, Warrandyte and Hepburn Springs, to the Dandenongs and Arthurs Seat in the east—could be disasters waiting to happen. These were examples of how dangerous some places in Victoria could be. Those on top of ridges were in danger of blowtorch-style fires which moved quickly up forested hillsides. Kinglake was devastated by a *blowtorch* fire. Other towns at risk were in hollows or open valleys and in danger of firestorms caused by a blizzard of embers falling from surrounding hills, such as happened in Marysville. The nature of the fuels and terrain in many of these places is what makes them so attractive [to live in] but also potentially disastrous as well. Other dangers were lack of access roads, transient populations, and houses built to capture tree-top views rather than to withstand bushfire. (Bachelard 2010a, 7)

It also is not beyond the bounds of possibility that fires will reshape the vegetation of these areas.

> Eucalypt woodlands would hold on in large areas of their current range, but even these fire-tolerant systems would be vulnerable to big, frequent fires, especially when El Niño droughts compound the effect of global warming. Fragmentation of ecosystems would limit the ability of plant communities to colonise more hospitable areas. Plants have to occupy intermediate zones. Migration isn't likely. (C. Jones 2010, 1)

Heavily forested "tree change" communities at the periphery of the metropolitan area, such as those in the Dandenong Ranges and North Warrandyte, are set in a maze of winding roads and dirt access tracks that quickly would become jammed with escapees. Similarly, in the coastal towns of Lorne, Aireys Inlet, Fairhaven, and Anglesea, an area destroyed by fires on Ash Wednesday in 1983, the forest has grown back and residents and summer numbers have ballooned, but the overcrowded Great Ocean Road remains the only way out.

Bushfire behavior is so complex it thwarts the type of fine-grained risk assessments needed to distinguish between what is probable and inevitable. The VCAT recently refused to grant permission for a family to build a house on its Yarra Valley land, in part because the tribunal thought the risk of bushfire was too great and the site fraught with danger (Cooke 2010). However, contemporary historical research on brushfires in Southern California could help Australia with an application of a computer model that predicts risk in narrow bands across a terrain according to spatial variation in extreme winds (Moritz et al. 2010).

As noted above, the royal commission examined the provision of safe refuges, but the government has yet to identify fully where these places may be situated in towns throughout the state (Lacey 2009; Victorian Bushfires Royal

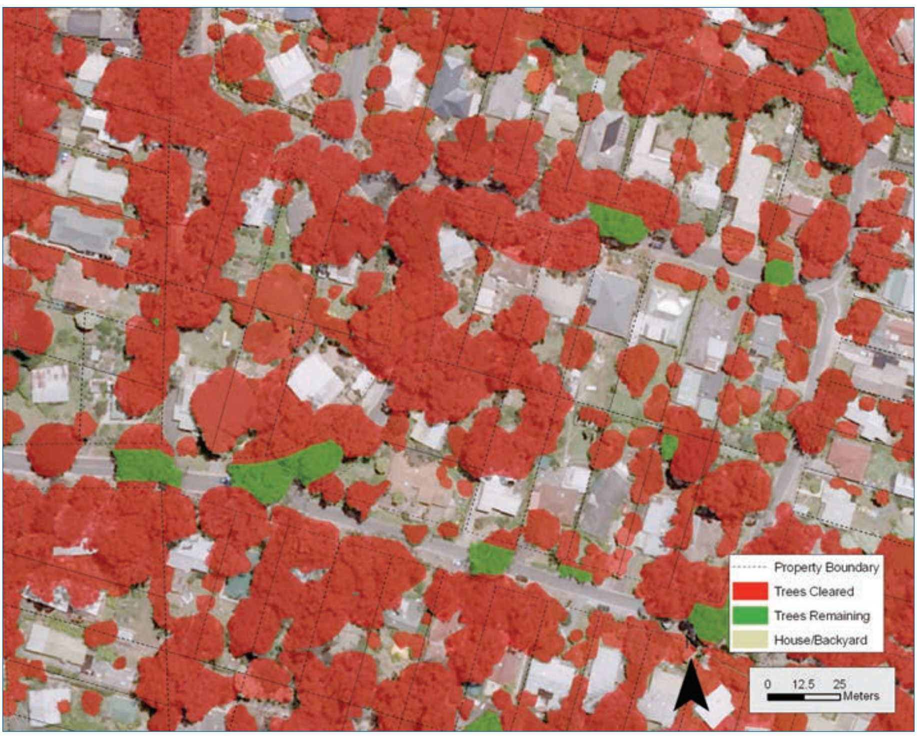
Commission 2009b). The commission recommended that the term *neighborhood safer place–place of last resort (NSP)* be abandoned in favor of *shelters*. This has not occurred, and NSP signs are already beginning to appear with the release of maps designating 85 percent of the state as bushfire prone (Dowling 2011b).

Fire Services Commissioner Craig Lapsley has signaled that in the future Victorians will be warned at the commencement of the fire season "that they face a high risk of trauma, injury or death" if they seek shelter in a place of "last resort," such as a local sports ground or a farm dam. He also urged parents on "extreme" or "code red" days to take children from schools before the first hint of fire (Gray 2011c).

The very intense fires that were experienced on Black Saturday would have produced a witch's brew of chemicals—aldehydes, volatile organic compounds, and fine particulates—as well as the deadly carbon monoxide that resulted through the reaction of water with elemental carbon. Clearly that level of toxics exposure, which could lead to long-term health consequences, would be better avoided by abandoning the affected areas altogether.

Fuel-reduction burns (FRBs) to eliminate or reduce the severity of fires have always been a point of contention between those wanting asset protection and those who favor habitat conservation. The evidence for the effectiveness of such burns has been very mixed, with the type of vegetation, terrain (ridgelines, etc.), and fire temperature all appearing to be critical variables. Geoff Lacey (2009, 10–11), for example, uncovers evidence from French Island forests near Melbourne "that an open under storey is not necessarily the result of frequent burning . . . [and] that frequent hot burning by settlers in some locations gave rise to a dense growth of trees and shrubs." He further cautions that frequent control burning in forests and other ecosystems "could result in changing the species composition and perhaps a change of the ecosystem from one type to another, for example, from a shrubby to a grassy under storey and vice versa."

A different viewpoint has been offered by a former forests chief, who told the royal commission that, over 30 years, successive state governments failed the people of Victoria by allowing forest fuels to build up to unnaturally high levels, creating fuel loads that significantly contributed to the high death toll on Black Saturday. He also called for tripling the annual FRBs' target to 385,000 ha, which should be mandated in law (Gray 2010b). According to Robyn Grant (personal communication 2011) of the Gippsland Environment Group, however, FRBs as presently constituted suffer from systemic problems that, if not remedied, could lead to wholesale destruction of species and possibly "the bush" as we know it. For example, the monitoring budget provides only 1 to 2 percent of the fuel-reduction budget and includes no fauna, fungi, invertebrate, or aquatic species monitoring. Nor does it accommodate water-quality monitoring. Moreover, the frequency of FRBs allows no time for seeding and regeneration, and the burns are not performed on a trickle-mosaic basis, which tend to be hot rather than cold burns and allow wildlife to take refuge in adjoining patches.



Before and after aerial views demonstrate how few trees would remain untouched (in green on second image) if residents of a 6.4-ha area at Upwey in Melbourne's Dandenong Ranges strictly followed new clearing rules legislated by the government of Victoria in the wake of Black Saturday.

Photographs: © Michael Buxton.

No less controversial is the issue of clearing around houses. In September 2009, under the concept of “defendable spaces,” the state government issued new rules, which stated that properties can be cleared of trees within 10 meters of a house and 4 meters of a fence line. Given the size of many subdivisions in peri-urban areas, this rule could result in a virtual stripping of the landscape. Michael Buxton’s aerial photographs show that, for a 4.6-ha area at Upwey in the Dandenong Ranges, only 12 of the existing 262 trees are safe from being felled. Apparently the only thing preventing this from happening is the expense to the property owner.

Ken Edmunds, a firefighter, has suggested that this kind of tree clearing could lead to fierce winds funneling through the denuded landscapes, spreading fires even farther and faster, and in any event fireballs that result from windborne debris could drop on any property (personal communication 2009). Concerns about how to respond to fire danger show up in the Country Fire Authority’s (CFA 2009, 4) preexisting information brochure about leaving early or defending your property: “If you chose to stay to defend, you must have adequate defendable spaces, be well prepared and understand the complexities and the risks of your decision, including *the very real chance you may be injured or killed*” (emphasis added).

A further response to the Black Saturday fires has been to develop a bushfire attack level (BAL) rating system in which homes are categorized in one of six bushfire levels, ranging from low to extreme, based on risk factors including the fire danger index, FFDI, slope of land, and vegetation. For example, the highest rating—BAL-FZ (flame zone)—would apply to the ridge along which Coombes Road runs in Kinglake West, where all homes were destroyed with a large loss of life. Outbreaks can occur wherein temperatures in excess of 1000°C make it unlikely that even houses conforming to the BAL scheme would be able to survive, however. A key royal commission recommendation that would have instituted a buyback of properties at high risk (e.g., BAL-FZ) was rejected by the then-Labor government, although the new coalition government has announced a limited, voluntary scheme (Gray 2011a). This has received a mixed reception from Kinglake property owners (Gray 2011b).

Although the burnt areas are to be rebuilt with more robust standards for fire resistance, they remain vulnerable. Even the most fire-resistant structures, especially those that are timber clad, would be at risk of destruction under weather conditions similar to those on Black Saturday. Thus a risk-reduction plan needs to be developed for the areas that escaped burning, where minor modifications to buildings at risk will prove both economically and socially acceptable. The same plan should apply to areas recently burned.

Finally, the royal commission has been told that, even though the government was warned as early as 2000 that cutting costs on power line maintenance could cause bushfires and pose a serious risk to workers and the public, nothing was done (Bachelard 2010b). Headed by a former St. Andrews resident who lost her son on Black Saturday, a class action against the distribution company SP AusNet, SPI Electricity is expected to go before the Victorian Supreme Court in 2012. The company is alleged to have failed to inspect and maintain its single wire earth return (SWER) power lines, which led to a break in a 43-year-old line that started a fire near Saunders Road in Kilmore East (Campbell 2011).

Meanwhile, at the close of 2011 the government announced a $500 million plan over 10 years to implement a recommendation from the royal commission to replace Victoria's 100,000 km of dangerous SWER lines. The government's plan calls for installation of a mix of aerial-bundled lines and underground lines, whereas the royal commission directed running all lines underground at an estimated cost of $40 billion. The government claims that this will reduce by 64 percent the risk of power lines starting a bushfire while achieving a 91 percent reduction from the cost for full undergrounding (Lucas 2011).

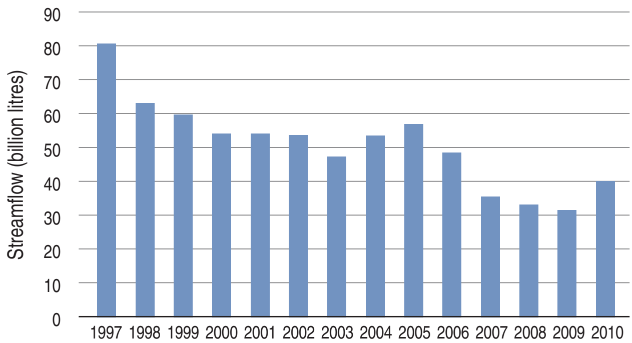
Nonetheless, the Powerline Bushfire Safety Taskforce (2011, 3) noted that "the majority of powerline-initiated fires in Powercor's and SP AusNet's areas in 2009 were started by multi-wire powerlines (typically 22kV): approximately 1.6 fires started for each 1000 km of multi-wire powerlines compared with 0.3 fires started for each 1000 km of SWER powerlines." In that respect, the government has adopted the taskforce's recommendations to mandate installation of rapid earth fault current limiters (REFCLs) that operate on 22kV power lines and new-generation automatic circuit reclosers (ACRs) for use on SWER power lines. Regarding priorities, the taskforce noted that "a large proportion of the state's fire loss consequence [the likely extent of damage from a bushfire] can be mitigated by targeting actions to a relatively small proportion of powerlines supplying a small proportion of Victoria's rural customers. These powerlines are mainly located in the Dandenong Ranges extending north through to the foothills of the Great Dividing Range, the Otway Ranges and the Macedon Ranges" (Powerline Bushfire Safety Taskforce 2011, 4).

Drought and the Decline in Water Storage Levels

Recent incidents. In contrast to the rapid onslaught of the fires, the drought was a protracted occurrence. A decline in rainfall began in 1998, and a sharp drop in drinking water levels reduced Melbourne's reservoirs to 25.6 percent by mid-2009—the lowest level ever recorded (figure 6.7). Above-average rain from 2009 into 2010 caused a turnaround, with dammed reservoirs refilling after 14 years of drought. Between 23 June 2009 and 21 November 2011, total system storage (TSS) rose 724 gigaliters (gL) representing a rise from 26 to 65 percent. The string of record-low levels set earlier took a corresponding toll on agricultural production. More records were broken when the water levels rose.

Drought implies that the particular state of affairs will come to an end at some point, which will be followed by a return to past rainfall and evaporative regimes. Modeling undertaken by CSIRO indicates that this is unlikely over the

Figure 6.7 Melbourne's Water Storage Levels, 1997–2010
Source: Melbourne Water.



long run, however, since water supply is projected to decline by 3 to 11 percent by 2020 (depending upon the warming scenario) and 7 to 34 percent by 2070 (R. Jones 2009).

David Dunkerley (2009) examined the intricacies of Melbourne's rainfall for 24-hour periods spanning a 68-year timeframe and found a shift to prolonged precipitation events characterized by lower rain rates and smaller event depths, all of which could potentially exacerbate the effects of declining annual rainfall. He further notes that a larger fraction of the incident rain is lost to wet-canopy evaporation during lower rain-rate events. In other words, smaller rain events are less able to penetrate leaf canopies and ground litter to replenish the soil's moisture store, while changes in subdaily rainfall may be of considerable significance to ecohydrology and to the production of water supply from forested catchments. Clearly this phenomenon had been instrumental in the decline in soil moisture observed earlier (Lopes and Osman 2010).

Lower rain rates and smaller event depths have provided conditions for the outbreak of fires within forested water reserves. Fire invaded the Maroondah, O'Shannassy, and Tarago reservoirs on and after Black Saturday, damaging 30 percent of Melbourne's catchments during a period when water consumption trebled. These events showed that surface water supply is not only in jeopardy from growing aridity, but subsequent heavy rainfall can wash mud, ash, soil, and rocks into the dammed bodies of water (the Tarago, Thomson, Upper Yarra, O'Shannassy, Maroondah, Greenvale, Yan Yean, Sugarloaf, Silvan, and Cardinia Reservoirs). This occurred after the Canberra fires and required filtration plant upgrades (White et al. 2006). Additionally, the water demands for recolonizing eucalyptus saplings can deplete run-off for 20 or more years. It was fortunate that only limited rain fell over Melbourne's catchments in the wake of 7 February 2009.

Policy responses. In the weeks following Black Saturday, water held in the storage areas at Maroondah and O'Shannassy, both of which had fire-damaged reserves, was sent to areas where there had been no fire, specifically the Silvan and Cardinia Reservoirs, to guard against heavy rainfall washing contaminants into them (White et al. 2003). Some 500 km of firebreaks 40 meters wide subsequently were cut around the Thomson and Upper Yarra catchments, which supply most of the city's drinking water, to protect 160,000 ha of vulnerable forest, based on the assumption that these efforts would make the catchments closer to 100 percent safe. Airborne burning bark and twigs, however, can ignite areas as far as 20 km ahead of an advancing fire and thus breach these buffers, especially with the kinds of temperatures, humidity, and winds experienced on Black Saturday.

The announcement in 2005 that the smaller Tarago reservoir was to be recommissioned was cast as a response to climate change, with the state government remaining opposed to building desalination plants or pipelines to tap into other water basins. The State Government of Victoria's Our Water Our Future initiative (DSE 2007) adopted the conclusion of the Melbourne Water Climate Change Study.

> Demand management measures and water supply augmentations identified in the Water Resources Strategy for the Melbourne Area were found to provide sufficient buffer for climate change to be adequate in 2020 across the full range of climate change and alternative demand forecasts considered in this case study. . . . After 2020 the magnitude of supply side changes may require additional action to be taken including desalination or other system augmentation. Melbourne Water's ability to cope with climate change will be dependent on the rate at which climate change, population growth and water use reductions occur. (Melbourne Water 2005, 18)

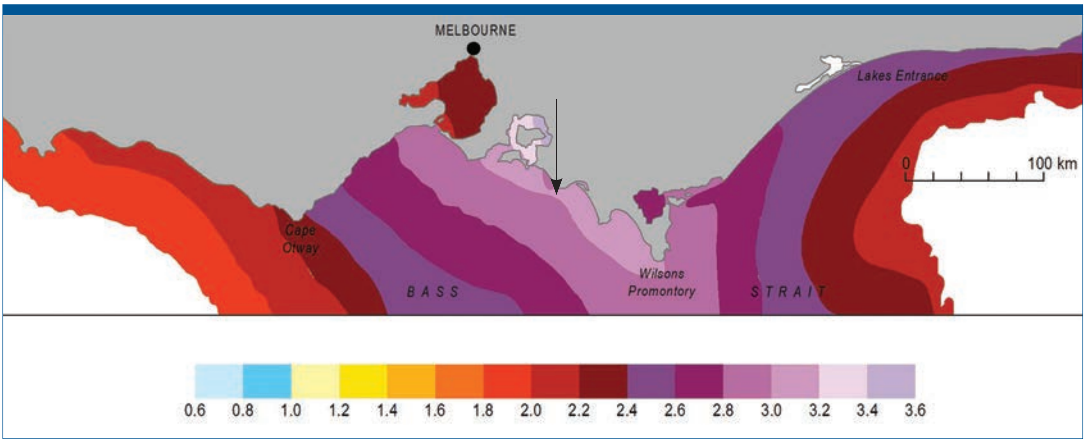
At the time, it was assumed that the drying was a phase and that wetter conditions would return (which, in fact, they did in 2010). Two years after Our Water Our Future got its start, the State Government of Victoria (DSE 2007) determined this perspective to be tenable no longer, and it released a water plan, again marketed as Our Water Our Future, settling for big engineering solutions rather than focusing on domestic water tanks and recycling, as many had urged (Parliament of Victoria 2009). Australia's largest reverse osmosis (RO) desalination plant, which is designed to produce 150 gL per annum—or one-third of Melbourne's water needs—remains under construction at Wonthaggi, southeast of Melbourne, a few hundred meters away from a high wave-energy coastline.

Multiple-effect desalination (MED) combined with gas-fired, combined-cycle electricity generation, an alternative method common in the Middle East, was overlooked. Such technologies use the heat exhausted from the turbines making electricity in gas-fired power stations to generate steam that feeds a turbine to make yet more electricity. The steam then can be condensed or sent to a distillation plant to produce freshwater. Combined-cycle installations have impressive fuel efficiencies, both in desalination and in pure power generation modes.

A public-private partnership is building the RO plant near the mouth of the Little Powlett River at a site that is vulnerable to inundation. Flooding that took place in 2007 was called a 1-in-100-year event by the state government, for example, yet it disrupted construction work when it occurred again in Febru-

Figure 6.8 1-in-100-year Storm Tide Height in 2100 Relative to Present-Day Mean Sea Level

Sources: McInnes (2011); McInnes et al. (2009).



Note: In harm's way? CSIRO modeling suggests that the Wonthaggi desalination plant (indicated by arrow) is especially vulnerable to storm surge under conditions of rising sea levels. Assumes a 19 percent increase in winds forcing the storm surge and 82 cm of sea level rise.

ary 2011 (figure 6.8). Opponents have numerous concerns: the brine load; disruption of rustic values; the need to put the rejected iron chloride used in the process in a landfill; and the plant's dependency, at least in part, on power generated from brown coal. Another problem is its close proximity to the ocean on a part of the southern coast that CSIRO has identified as the most vulnerable to storm surge and sea level rise (Department of Climate Change 2009; McInnes et al. 2009).

Once the plant comes online, water prices are expected to rise 64 percent, and it is planned to continue producing water until Melbourne's reservoirs reach 65 percent capacity—a TSS level attained on 21 November 2011. When originally announced in 2007, the cost was $3.1 billion, which rose to $3.5 billion after farmers demanded that feeder power lines from the Latrobe Valley that cross their properties be put underground. Then the winning consortium said that the full cost, including operating expenses, would be $4.8 billion with financing. In late 2009 the government tabled a document showing the cost would be $5.7 billion. Kenneth Davidson (2010, 11) observed, "even if the plant produces nothing, the government will be forced to pay under its contract $570 million a year for 30 years. This is equal to $3.80 a kilolitre without the supply of any water."

The government's 2007 water strategy had another key element: public-private partnerships building pipelines to move water within or between basins, known in current water parlance as a *water grid*. The key pipeline, the North-South or Sugarloaf, was conceived as an insurance policy for providing a supplemental water supply until the Wonthaggi desalination plant came online. It was intended to transport water from a then-depleted Goulburn River (a tributary of the Murray-Darling) to a holding reservoir at Sugarloaf. The pipeline was predicated on a 225-gl-per-annum water savings further downstream in the Goulburn Valley, primarily because it was expected to eliminate evaporation and seepage losses in irrigation channels as part of a broader "food bowl" plan. The Victorian Auditor-General's Office (2010) has since found that the government failed to demonstrate the need for this expenditure and to properly explore alternatives.

The new minister for water has stated that moving water through a water grid from one community to another deprives a farming industry reliant on the water in the former community, however (Walsh 2011). The government has since mothballed the North-South pipeline in favor of emphasizing water security by increasing recycling initiatives for both water and stormwater (Arup 2011). The minister also expressed concern about the water-saving estimates in Northern Victoria and asked the state ombudsman to look at the oversight and governance of the irrigation modernization project there. The ombudsman subsequently reported that the project has "an ongoing battle" with technical problems, poor contractor work, and faulty equipment (Fyfe 2011, 2).

Both the desalination plant and interbasin pipelines represent a shift to carbon-intensive solutions. Forcing seawater through ultrafine membranes or pumping raw water over mountain ranges consumes large amounts of electricity, which translates into even greater emissions and requirements for yet more water for cooling at the power stations. These energy-greedy projects are being superimposed onto existing and planned carbon-intensive wastewater treatments that are struggling to be offset by methane capture, pumping efficiencies, and other measures.

In 2007 the government at the time had maintained that the increased energy demands could be countered by renewables. In Perth, Western Australia, for example, 48 wind turbines were built to compensate for the coal- and gas-fired turbines that powered the Kwinana desalination plant. Fully operational, Australia's fledgling RO water desalination plants could release up to 6,000 metric tons of carbon dioxide emissions from the nation's coal-fired power stations. At this rate, wind farms hardly dent the growth in national GHG emissions.

The change from a predominantly gravity-fed potable water supply via mountain dams to volt-driven processes can potentially push the water industry toward an even greater dependency on the electricity sector. That deepening connection requires new organizational approaches to keep abreast of the technological changes. But the lack of technical direction within the state government that resulted from outsourcing appears to have clouded recognition of the opportunities this presents.

Victoria urgently needs to retire its less efficient, dirty, brown-coal-fired stations, and the state's former Labor government had sought federal funding to decommission the Hazelwood plant. Early in 2011, however, the new

The Yarra River discharges its plume of sediment and pollutants into Port Phillip Bay in the wake of massive rainfall during February 2011.
Photograph: © Mike Abicare.

coalition government abandoned that plan. Nonetheless, the introduction of a national carbon price in Australia from July 2012 included a request for expressions of interest from high emission power stations to offer to close down. While Hazelwood has expressed an interest, it has made no final decision whether to accept a closure offer. Price will play a large part, but inevitably gas base load progressively will replace existing capacity or meet additional demand through a combination of a carbon price and banks' reluctance to lend to coal-fired projects. High-performance, low-carbon, gas-fired, combined-cycle plants with a capacity for distillation could replace the Hazelwood station and other aging installations.

Given that Victoria earlier faced a water deficit of considerable proportions, which was compounded with the need to move from dirty, low-efficiency, coal-fired power stations toward natural gas, it is difficult to comprehend how the Gulf states' successful model for integrating electricity generation with water making—that is, gas-fired, combined-cycle plants linked to multiple-effect distillation—could have been overlooked had it not been poorly understood. This appears to reflect the fact that energy and water policy development operate in separate silos. Upon such lines, in 2010 Australia's then-Chief Scientist Penny Sackett, referring to her report Challenges at Energy-Water-Carbon Intersection (PMSEIC 2010), expressed doubts as to whether budgets around the nation for energy, water, and carbon were being dealt with holistically. She added that treating one independently could harm the others (Fisher 2011a).

In the short term, at least, the existence of the Wonthaggi RO plant appears to have ruled out any consideration of an integrated installation at, say, Hastings on Western Port Bay, which has Longford gas and where brine concentrate could be sent to the Eastern Treatment Plant effluent outfall.

Nevertheless, opportunities remain for smaller water energy projects that scavenge waste heat and/or combustible gases from industrial sites, especially refineries, power stations, and gas plants, to run small MED systems—which are commonplace in ships and sugar refineries—to turn seawater or brackish bore water into process water. These alternatives could, at the same time, circumvent transmission line losses by as much as 20 percent due to the distance between the user and the base-load generator. Wind farms or wave farms, then, could be turned to other uses, thus further lowering transmission line losses. The possibilities are many and varied, and they suggest the scope of effort needed to both ensure water security and limit emissions growth.

Washed Out: Challenges and Experiences Under La Niña Conditions

Recent incidents. Record rainfall during February 2011 resulted in flash flooding in Melbourne. As much as 100 mm of rain fell within 75 minutes in some parts of the city. The impact on the Yarra River—sometimes known as "Melbourne's No. 1 Drain," as it threads through the metropolis and into Port Phillip Bay (Otto 2005)—was especially dramatic, with plumes of fine clay sediments as well as cigarette butts, topsoil, dog droppings, and other rubbish carried off city streets, testimony to the spread of paved surfaces. In addition, beaches experienced elevated levels of *E. coli* resulting from a pulse of sewage released from overloaded mains. The drainage authority, Melbourne Water, admitted that raw sewage was pumped into the city's rivers during this period. The storm was subsequently recorded as a 1-in-500-year event, but drainage systems in newer areas were designed to cope with only a 1-in-100-year event—a national standard clearly in need of review. Testimony to the inadequacy of basing return intervals on past weather records when dealing with climate change was the virtual repetition on Christmas Day 2011 of the 1-in-500-year event of the previous February. Once again, less than one year later, the city was lashed by violent storms, flash flooding, and even a tornado (*The Age* 2011).

Rebuilding older parts of the metropolis at a higher density is leading to vast expanses of paved and other hard surfaces that create urban heat island effects, lowered infiltration levels, and greater run-off. Drainage systems are being challenged by this creep of concrete, masonry, and asphalt—a situation not unlike that in the United States, where paved surfaces now account for an area the size of Ohio (Frazer 2005).

Policy responses. In 2005, the Victorian Auditor-General's Office (2005, 5) concluded that "there was little evidence that effective strategies had been applied to address [the] flooding risks. Because of this lack of progress, metropolitan Melbourne will continue to face significant flood-related damage" (Fisher 2011b). The situation has only worsened since that report, with infill housing increasing run-off volumes where hard tarmacs and roofs are displacing garden beds, turf, and trees. An architect who designed a block of three-story apartments in a middle suburb among those earmarked "to maximize development along new and future road based trunk public transport corridors" was ordered to install a large water pump in the basement car park, which would also flood, but he noted that no adequate main drain to absorb high-velocity stormwater was in place (Victorian Department of Transport and City of Melbourne 2009, 6).

A Melbourne Water report has warned that by 2030 the city's drainage infrastructure will be overwhelmed almost twice as often, and the area affected by flooding may be 25 percent larger across most parts of the metropolitan area (Ker 2011). This means more of the city will be vulnerable to inundation by 2030, as the same aging drainage system struggles to evacuate water from storms that are expected to produce 30 percent more rain by 2030. Philip Pedruco and Rod Watkinson (2011, 12) conclude, "This change in rainfall intensities may have significant implications on future planning, management and infrastructure. . . . We may need to revise our infrastructure design standards, and some areas currently considered appropriate for development may be vulnerable in the future."

Policy Directions: Aspirations for the Decade Ahead

Reconfiguring large parts of Melbourne to cope with a future punctuated by severe deluges obviously is required. In particular, introducing vegetated areas would help attenuate flows, since trees and shrubs adsorb raindrops on their leaves, their roots soak up further amounts, and grass surfaces allow infiltration. More immediate responses are needed, however, which could include restricting construction of underground shops and facilities, such as car parks, and shifting auxiliary generators from basements to higher levels to lessen risks to communities, businesses, and critical infrastructure in order to aid recovery in the event of flooding. Developing a risk map of the metropolis that covers bushfire and storm surge as well as inundation could aid in data collection.

Areas developed before the late 1970s are especially vulnerable. Their space limitations make it difficult to retrofit them with features such as retarding basins to store water and guide it into waterways and the sea—although an occasional park or sports oval might be used for the purpose. In more favorable circumstances, much of the discharged water could be harvested after the first flush and thence cleansed.

Billions of dollars will be needed to secure these older areas from the worst impacts of climate change. Unfortunately, in the contest for capital, drainage systems receive low priority compared to infrastructure that is viewed as directly boosting economic growth, such as the federal government's National Broadband Network, despite the fact that its systems can be seriously disrupted by inundation.

A public-private partnership between the government and the insurance industry that funds mitigation of riverine flooding might be adapted to address the cause of city flash flooding. Another possibility is levying an impervious-service charge, such as the one in Richmond, Virginia, and many other municipalities in the United States, "to areas that have been paved or otherwise covered with material that is resistant to infiltration by water" (Richmond Department of Public Utilities 2011).

It also has been suggested that the existing built-out city can yield large areas for renewal, and the Victorian Auditor-General's report (2005) can serve as a forewarning that substantial hidden costs associated with building out may occur in some locations. Developers who see planners as roadblocks should be made to wait while careful assessments of flood risk and storm surge under new weather conditions are studied further and become better understood. For example, Melbourne Water intends "to review the performance of the total drainage system in order to ensure its optimum capacity into the future" (City of Casey 2011).

There is no ready-made solution to protecting lives, assets, and wildlife from firestorms. A relentless urban expansion driven by strong population growth is causing the destruction of valuable habitat, the potential extinction of native birds and mammals, and the loss of food-producing land. Significant levels of densification proposed as a solution are now leading to vast expanses of hard surfaces that create urban heat island effects, lower percolation, and intensify run-off as noted earlier. Far more sympathetic treatments are possible (Fisher 2007).

In many parts of the city fringe the fire risk is so great that residential development there should be prohibited—especially in the absence of provisions for compulsory evacuation ahead of code-red conditions—and this ban ought to extend to new development and the subdivision of existing areas (Buxton et al. 2011; Gray 2010a). Moreover, the possibility of a fundamental shift in vegetation type due to more frequent, hotter blazes and global warming should oblige a more extensive government buyback of privately owned land in all high-risk areas. This should also prompt serious thinking about population growth in such places. The previous state Labor government rejected a voluntary buyback scheme proposed in the final report of the Victorian Bushfires Royal Commission (2010), while the opposition at the time, which since has become the coalition government, said it would implement that recommendation. It has now done so, but on a very limited basis by applying the scheme only to properties affected by the 2009 bushfires, which have yet to be rebuilt, and not to other areas at unacceptably high risk for bushfires (Gray 2011a; Urbanalyst 2011).

The combination of dryness and intensive population growth still besets Melbourne's water security. The Labor government had addressed this situation by building a north-south pipeline and a huge RO plant. Apart from an enormous public debt burden, however, these large-scale engineering projects move the water industry toward an even higher dependency on the generation of electricity, thus increasing its vulnerability to the kinds of power shortfalls predicted for the decade ahead. Even if renewable sources are brought into play, the reliance on electricity seems likely to increase Victoria's GHG emissions. It also highlights the need for a greater degree of integration between water making and electricity generation, which is possible with combined-cycle, gas-fired power stations through MED technologies accompanied by greater organizational integration.

A recent report by the U.K. Environment Agency (2009) suggests that water companies merge with energy producers to create more effective partnerships for tackling emissions. The conundrum for Victoria is that the generators are privately owned whereas the water utilities are public. One way or the other, the local water industry and the government clearly have some work to do if they are to lower the industry's carbon footprint in a significant way. The efficiencies arising from integration of the two sectors should not be underestimated.

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Resilient Coastal City Regions

Planning for Climate Change in the United States and Australia

Edited by

Edward J. Blakely *and* Armando Carbonell

Resilience is the new sustainability, especially for coastal cities and regions facing a potent mix of climate change shocks and impacts. Blakely and Carbonell have assembled an impressive set of cases and authors, likely the single best source of information about climate change planning and adaptation in the United States and Australia. The book provides a rich array of ideas, best practices, and innovative solutions for tackling climate change, and is essential reading for planners, citizens, or public officials involved in charting the future of coastal cities and regions. This collection of cases will inform, motivate, and inspire other coastal urban regions in simultaneously adapting to and mitigating global climate change. The book provides a badly needed dose of hope—that coastal cities and regions around the world have the power to take tangible and effective steps to confront and plan for climate change, and can provide essential leadership in times of national and international complacency and inaction.

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Teresa Heinz Professor of Sustainable Communities
School of Architecture, University of Virginia

The United States and Australia share many common social and political traditions, continental landscapes with diverse climatic conditions, and major coastal population and commercial hubs with vast interior hinterlands. In the past several years, both countries have been hit by acute natural catastrophes, reminding us of our shared environmental fragilities. These similarities serve as the template for this book on regional adaptation and sustainability planning to mitigate the potential damages. This is a book for both policy makers and scholars, to help us deal more effectively and efficiently with the increasing confluences of natural disasters and climate change on dense metropolitan areas.

— Robert Hill
Chairman, Low Carbon Australia
Chancellor, University of Adelaide
Former Australian Ambassador to the United States

Mounting evidence reveals ever-faster, more extreme, and more uncertain outcomes in spheres climatic, economic, and so on; earth's revenge may be sooner than we expect. We must do more than adapt and mitigate, we must reduce and prevent. These are now imperatives, and the only way to reach a future worthy of its name is to plan, especially in our most vulnerable ecotones, such as coastal cities. This book, by masters at their games, shows us how. It is now our turn to act, using their sage advice.

—Michael Neuman, AICP
Professor of Sustainable Urbanism, University of New South Wales

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