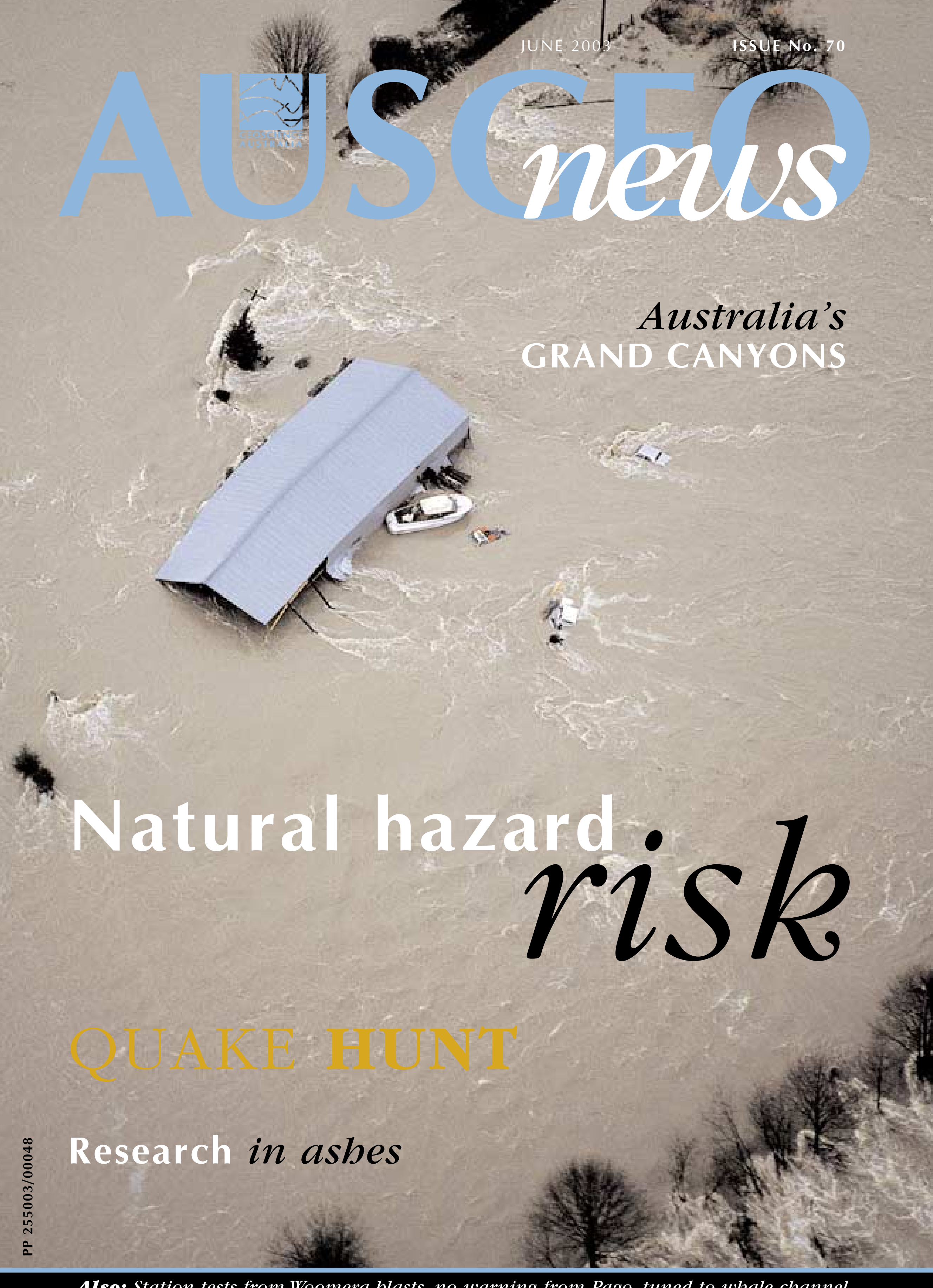
JUNE 2003 ISSUE No. 70

AUSGEO *news*



Australia's
GRAND CANYONS

Natural hazard *risk*

QUAKE **HUNT**

Research *in ashes*

PP 255003/00048

Also: *Station tests from Woomera blasts, no warning from Pago, tuned to whale channel...*

AUSGEO News
June 2003 Issue no. 70

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Floods are Australia's most costly natural disaster causing 99 deaths, more than a thousand injuries, and averaging $314 million in damages annually from 1967–1999.

Most of us don't think about flooding and other natural hazards until they happen. Only then do we realise how vulnerable we are to natural hazards and how imperative it is to assess community risk.

Photo: © Australian Picture Library

In the Federal Budget released on May 13, there was a major investment in offshore oil exploration.

Geoscience Australia will receive $61 million over four years to locate opportunities for oil and encourage exploration in Australia's offshore.

The money will be used in two ways: $36 million is to provide basic geological data about potential offshore petroleum reserves, which is essential to Australia's annual petroleum acreage release program.

This program has been under scrutiny recently. But the Federal Budget recognises that this work is crucial and confirms that it is a core function of Geoscience Australia.

The remaining $25 million is for collecting new seismic data in under-explored areas, and for preserving vast quantities of data.

More than half a million data tapes held by Geoscience Australia need to be copied onto modern storage media. Valuable seismic data belonging to the nation now won't be lost because of deteriorating old-technology tapes.

In another exciting development, our geohazards research has major applications for national security—one of Australia's new national research priorities.

The databases and risk models we are developing to address natural hazards are in demand for such national security issues as terrorist threats to communities and their critical infrastructure.

We demonstrated our capability to address these threats with a terrorist-attack scenario at the Prime Minister's Science, Engineering and Innovation Council in December last year.

The data and methods we use to estimate the potential damage to critical infrastructure and loss of life from sudden impact events apply to both natural and human-induced hazards. The common ingredients are 'risk' and 'spatial data'.

Natural hazards cannot be averted, but governments can reduce the effects by knowing the potential risk, identifying the areas that are most vulnerable and recommending precautions or mitigation measures. Effective mitigation can include improved building codes and land-use planning, as well as education and community awareness.

In this context the Council of Australian Governments commissioned a review of natural disaster relief arrangements in Australia. One key recommendation of the review is to 'develop and implement a five-year national program of systematic and rigorous disaster-risk assessments'.

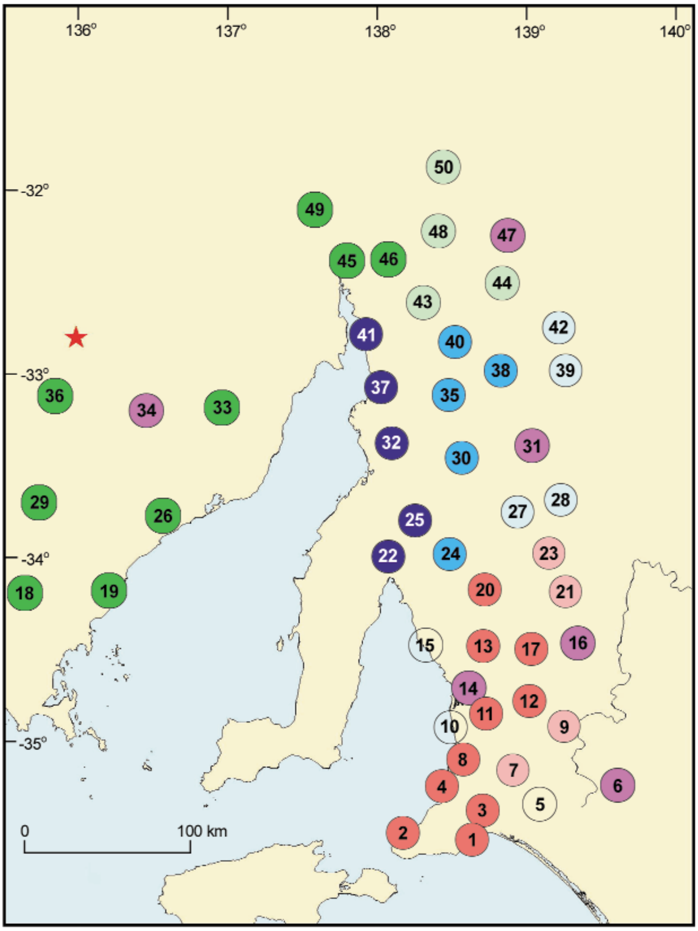
Since the inception of our Cities Project in 1995, Geoscience Australia has been a leader in the development of natural hazard risk models and methodologies. As a consequence, we have been invited to help develop a national framework for risk assessments.

In this issue of *AusGeo News* we give you an insight into some of the geohazards research currently being carried out by Geoscience Australia, which is so vital to the nation's well-being and security.

Comment

NEIL WILLIAMS
CEO Geoscience Australia

Small moves towards a BIG EVENT in South Australia



A major earthquake has not shaken South Australia in 49 years. But it will happen again.

Of all the nation's capitals, Adelaide has the highest risk of a major earthquake occurring. There have been more moderate-sized earthquakes near Adelaide in the past 50 years than any other capital city in Australia. And the Mount Lofty and Flinders ranges have had a steady level of activity for at least the past 150 years.

South Australia is being squeezed at a rate of about 0.2 millimetres a year. This movement or compression over many years causes so much crustal stress that an earthquake occurs.

The last big earthquake near Adelaide of magnitude (M)5.4 was on March 1, 1954, near Darlington. The biggest recorded quake in the state was at Beachport in 1897. It measured M6.5.

An area that gets these sized earthquakes is likely to experience another event in the future. Scientists don't know, however, whether it is a one in 50-year event or a one in 500-year event.

But they do know that the Mount Lofty Ranges are being compressed in an east–west direction, and that Adelaide and Murray Bridge are slowly moving together at perhaps a tenth of a millimetre a year.

They also know there are a number of faults in the Adelaide region. The 1954 earthquake is thought to have occurred along the Eden–Burnside Fault that runs from Marion Rocks through Seaford to Tea Tree Gully.

Respite leaves *Burakin quaking* in anticipation

A magnitude-five earthquake (M5) occurred 10 kilometres west of Burakin, in south-west Western Australia on September 28, 2001. In six months, there were three more magnitude-five earthquakes and 18 000 smaller earthquakes.

Some residents in the region felt thousands of these earthquakes. Burakin felt several hundred. Many buildings within 25 kilometres of the activity suffered minor damage, but none has major structural damage.

Since September last year it has been quiet on the western front. Geoscience Australia has seismographs in place, ready to record and analyse the next sequence of activity.

Seismic zone

Burakin is in the South-west Seismic Zone (SWSZ), Australia's most seismically active region for the past 40 years. The zone's centre is 150 kilometres east of Perth and approximately 100 kilometres wide (figure 1).

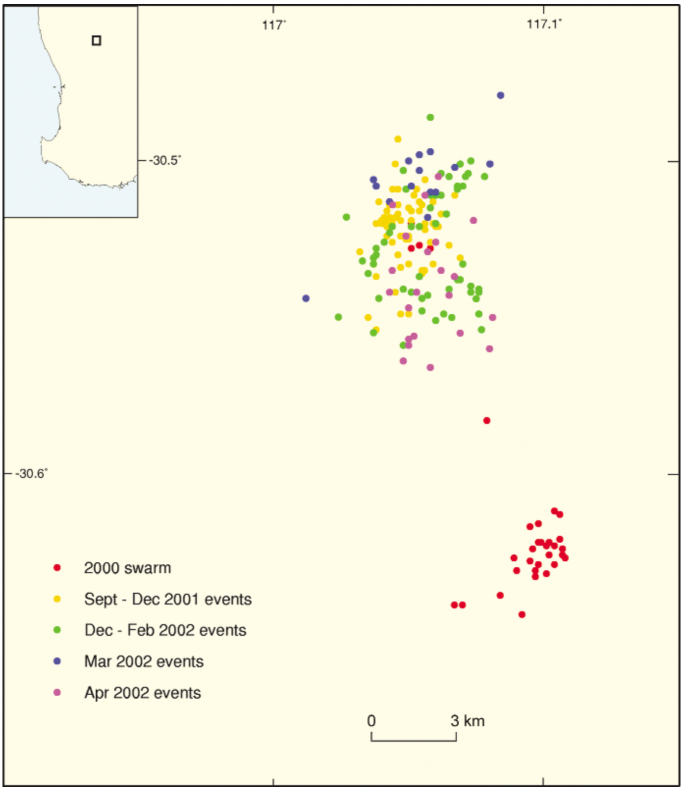


Figure 1. Map of earthquakes in the Burakin area since September 2000. The red earthquakes are from the swarm that occurred 12 months before any of the large earthquakes. The other colours represent the four largest earthquakes and their aftershocks.

As the stress builds up, eventually there will be enough compression to cause a big earthquake somewhere in the Mount Lofty or Flinders ranges.

But the movement is so small, that satellite technology is needed to detect it.

On May 2 the Minister for Foreign Affairs and federal member for the South Australian electorate of Mayo, Alexander Downer launched a five-year survey to assess earthquake risk in Adelaide and the Flinders and Mount Lofty ranges.

Geoscience Australia's Neotectonic Earthquake Hazard program is conducting this research in collaboration with Primary Industries and Resources South Australia, the South Australian Department of Administrative and Information Services, the Australian National University, and the New Zealand Institute of Geological and Nuclear Sciences.

Fifty survey marks have been installed in the Mount Lofty and Flinders ranges and the eastern half of the Eyre Peninsula (see figure on page 4). GPS (global positioning satellite-system) equipment was set up on the survey marks for a week to pinpoint their location to within one-millimetre accuracy. Temporary seismographs were deployed to more accurately detect and locate any earthquakes during the survey.

In five years' time the survey marks will be 'reoccupied' to measure any movement among the sites.

Geoscience Australia will combine data from this survey with recordings from earthquakes in the area to estimate when the next big earthquake is likely to shake South Australia.

For more details phone Mark Leonard on +61 2 6249 9357 or e-mail mark.leonard@ga.gov.au

The SWSZ has had several significant earthquakes. The 1968 Meckering (M6.7) and 1979 Cadoux (M6) earthquakes ruptured the surface producing fault scarps 30 kilometres and 15 kilometres in length, respectively. Both earthquakes had aftershock sequences that lasted many years.

In February and March 1982 the town of Manmanning, 40 kilometres south of Burakin experienced an earthquake sequence similar to Burakin. But the high level of activity lasted only two months.

The Burakin activity is the highest level of seismic activity experienced in Australia since the 1988 Tennant Creek M6.7 earthquake.

Seismic stations

Geoscience Australia operates seven permanent seismic stations in south-west Western Australia. After the September 2001 earthquake, it also placed temporary seismographs in the area. For most of 2002 Geoscience Australia had nine seismographs within 100 kilometres of Burakin.

Because of Australia's size and sparse seismic activity, it is rare to have more than one seismograph within 100 kilometres of an earthquake. But the temporary seismographs near Burakin allowed Geoscience Australia's seismologists to locate earthquakes with unprecedented accuracy.

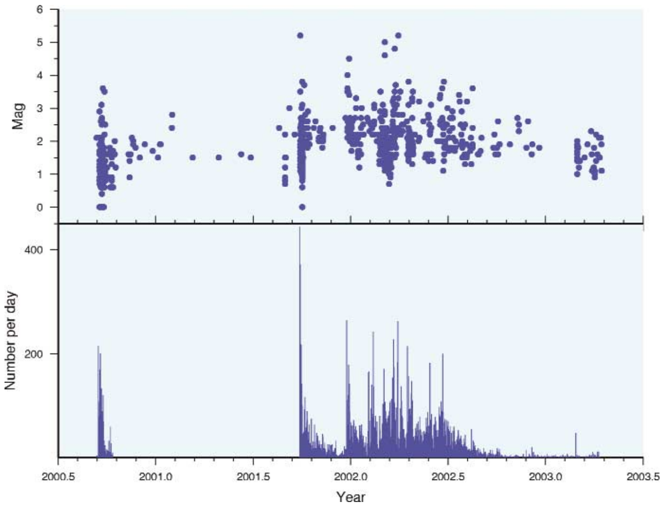
Australian earthquakes typically have a location uncertainty of 10 to 15 kilometres. In the SWSZ, 200 earthquakes have been located to within two kilometres. As well, the two M5+ earthquakes in March 2002 were recorded on high-fidelity equipment close to the epicentres. These are the best recordings of large earthquakes in Australia.

Quiet periods

The Burakin sequence began in September 2000 with a swarm of 1700 earthquakes, the largest of which had a magnitude of 3.6. This swarm lasted a month, after which the region was quiet for almost a year until the first M5 event. By May 2002 the earthquake activity started to peter out and has been relatively quiet since September 2002.

Earthquake location

The Ballidu seismic station 40 kilometres away from Burakin has recorded 21 500 events. Of these, about 750 have been located (see the earthquakes plotted in the top half of figure 2).



To locate an earthquake it needs to be recorded on four stations. For the Burakin sequence this means that only earthquakes above magnitude 2.0 were routinely located. Most of the other 20 750 earthquakes were smaller than M1.

Figure 1 shows the 200 best-located events, colour coded to indicate whether they are associated with the initial swarm or are aftershocks of one of the four M5 events. All these earthquakes were in the upper five kilometres of the crust.

The swarm events covered a much wider area than the earthquakes that followed. They seem to connect the current Burakin activity to the 1970 Cadoux earthquake that formed a 15 kilometre fault scarp, the northern tip of which is immediately south of this map at longitude 117.15.

The four main events and their aftershocks are clustered together. The March and April events respectively seem to be north and south of the September and December events.

Various earthquake relocation techniques (such as Joint Hypocentre Determination and Double Difference Relocation) will be applied to this data to refine the relative position of the various earthquakes. It might also be possible to determine the size and orientation of the actual fault plane(s). This would be very valuable in understanding the relationship among fault size, earthquake magnitude and energy release in Australia's earthquakes.

Mainly aftershocks

The histogram in figure 2 shows the number of earthquakes from the sequence recorded each day at Ballidu, the nearest permanent station. The earthquakes recorded at Ballidu range from magnitude 5.2 to 0.5.

Most Burakin earthquakes are aftershocks of the six largest earthquakes, which are listed in table 1. Numerous aftershocks after a large (>M5) earthquake are common in the SWSZ.

Central and South Australia also often have aftershock sequences with large earthquakes. In eastern Australia they are less common.

Decay rates

Graphing the number of earthquakes per day clearly shows changes in earthquake activity. The daily events for the Burakin earthquakes are plotted in figure 3. Some of the main features of these plots are:

- The first 89 days show a classic aftershock decay sequence with an Omori decay rate* of 1. In other words over a period of 100 days, the number of earthquakes per day is reduced by a factor of 100, in this case from 500 to 5.

Figure 2. The Burakin earthquake sequence from July 2000 to April 2003. Each dot represents one of the 750 earthquakes that have been located. The variation in smaller earthquakes reflects inconsistencies in the analysis criteria of earthquakes smaller than magnitude 2.5. The histogram shows the daily number of earthquakes recorded at Ballidu, the nearest permanent station of the national network.

- On day 90 (December 28) there is a marked jump in activity which coincides with the magnitude 4.5 event. Over the next 40 days there is a gradual decline with an Omori decay rate of about 0.35, corresponding to a drop from 300 to 20 per day.
- On February 4 there is another marked jump in activity with no clear decay in the activity over the following 150 days until late June 2002.
- From late June the activity decays for the next 100 days, with an Omori decay rate of 1. By mid-October 2002 the activity has petered out, except for a small spike in late February and early March 2003.

These observations suggest that the original M5 event in September 2001 is a main shock followed by a typical aftershock sequence lasting until December. The activity from January to June 2002 is probably a series of overlapping aftershock sequences, which give the appearance of relatively constant activity.

Aftershock magnitude

Worldwide, for every magnitude five earthquake, 10 M4 earthquakes are expected, 100 M3 earthquakes, 1000 M2 and so on. Seismologists call this the Gutenburg–Richter relation with a b value of 1.

The b value of the Burakin sequence is less than 1. With seven earthquakes between 4.3 and 5.2, a b value of 1 would predict 500+ earthquakes between 2.3 and 3.2. There have only been 170, however, giving a b value of about 0.7. This figure is consistent with b values calculated from aftershock sequences worldwide, where b values are typically in the range 0.1 to 0.8.

Stress transfer

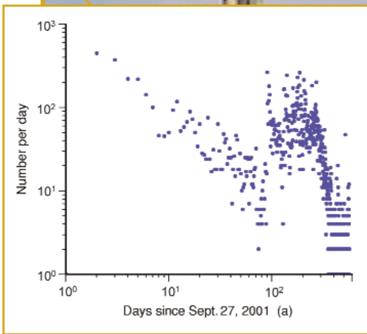
Another interesting observation is that the Burakin swarm (September 2000 to September 2001) occurred in four distinct zones on a 40-kilometre line. Normally such small earthquakes (just three were above M3) should only affect the stress in the crust up to a few kilometres away, but certainly not 20 kilometres away.

It appears that some kind of stress transfer process, such as fluid flow or creep in the lower crust, is causing the Burakin earthquakes to align in this pattern.

How stress is transferred in the Australian crust has important implications for understanding where and how often large earthquakes might occur in Australia. This is one of many questions raised by the Burakin sequence that Geoscience Australia seismologists are attempting to answer.

For more information phone Mark Leonard on +61 2 6249 9357 or e-mail mark.leonard@ga.gov.au

* Omori decay rates of 0.8-1.8 are typical for aftershock sequences of large earthquakes up to M6, and decay rates of <1.0 are typical for foreshock sequences. For example, the 1987 Tennant Creek foreshock sequence had an Omori decay rate of 0.25. The 1988 aftershock sequence had a decay rate of 1.0.



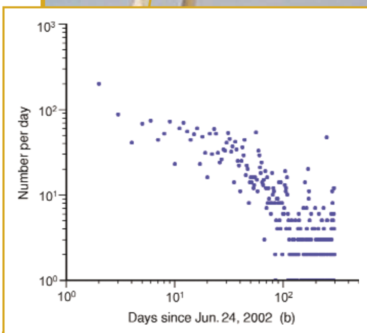
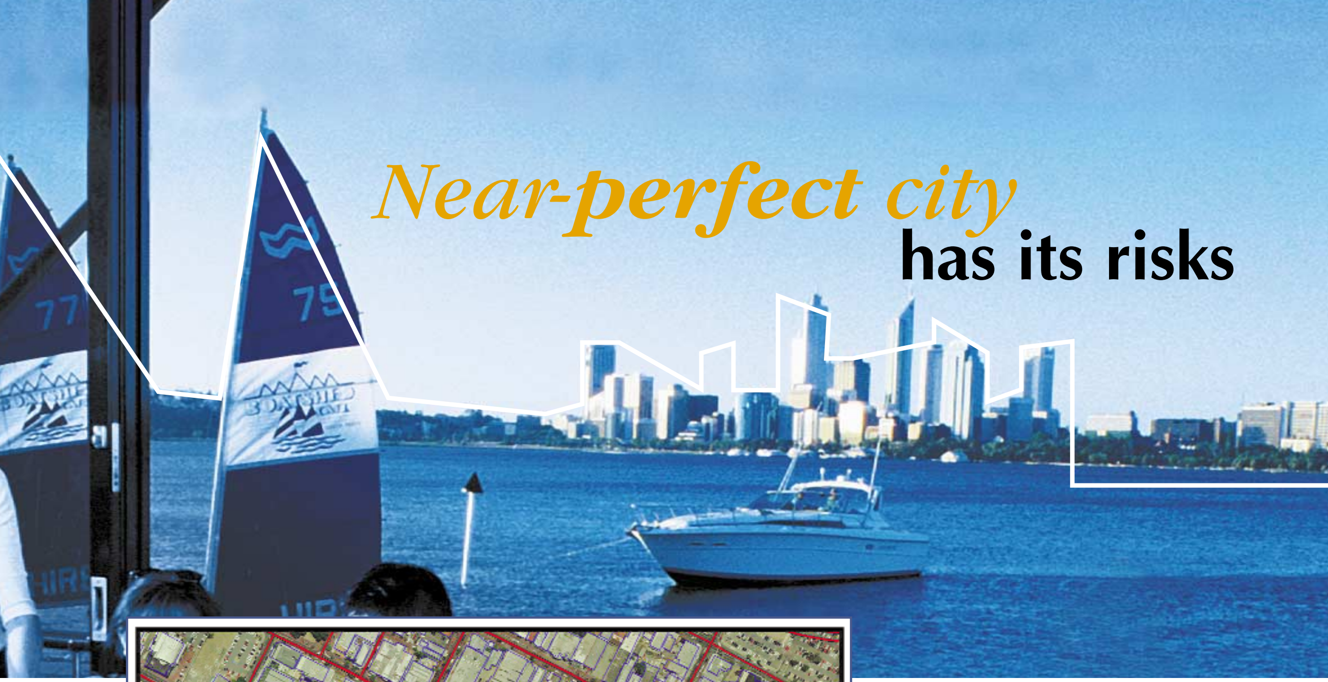


Figure 3. Number of Burakin earthquakes observed per day plotted on log-log scales: **a.** For 600 days since September 27, 2001 **b.** For 300 days since June 24, 2002

Table 1.
Origin information for five earthquakes in the Burakin series with magnitude 4.5 or greater

Date	Time UTC	Latitude	Longitude	Magnitude
28 Sep 2001	02:45:56.6	-30.49	117.05	5.0
28 Dec 2001	16:31:36.5	-30.56	117.05	4.5
05 Mar 2002	01:47:39.2	-30.49	117.10	5.1
05 Mar 2002	03:29:57.8	-30.50	117.08	4.6
23 Mar 2002	13:16:24.1	-30.41	117.44	5.1
30 Mar 2002	21:15:48.0	-30.41	117.44	5.2



Near-perfect city has its risks

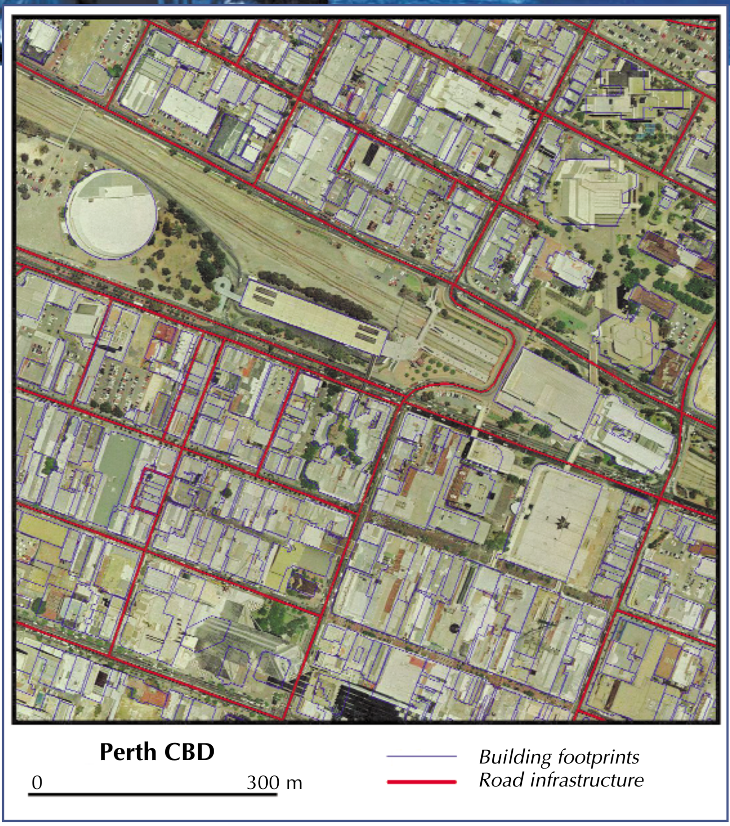


Figure 1. Map of Perth's CBD showing transport 'lifelines'—one of many pieces of information compiled in risk assessments

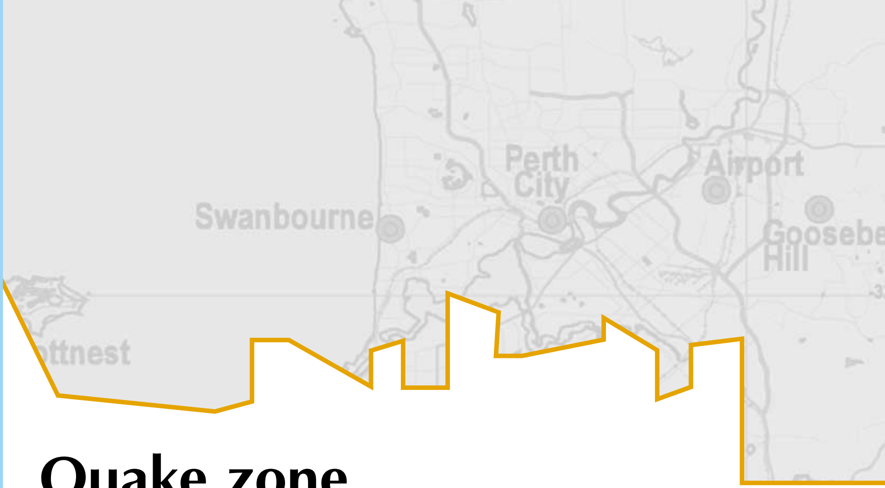
Nestled in the south-west corner of Australia is the very livable city of Perth. With plenty of sunshine, summer averages of 29 degrees Celsius and mild wet winters, Perth residents claim they have the climate that Californians desire.

So why is Perth and its near-perfect weather under the scrutiny of Geoscience Australia and its state and local government partners?

Perth is subject to natural hazards, and 72 per cent of Western Australia's population, or about 1.3 million people, live in Perth. It is near Australia's most active earthquake zone, sits beside the Swan River that floods, and is buffeted by high winds and fierce storms.

Any one of these natural hazards can be severe and devastate a community.

Geoscience Australia is modelling the frequency of such events and the potential damage to Perth's buildings and infrastructure. This research involves city planners, emergency managers, and agencies that administer water and power supplies so that they can make informed decisions about natural hazard risks.



Quake zone basis for PERTH MODEL

There has been a lot of earthquake activity in recent decades just east of Western Australia's capital, Perth, in an area known as the South-west Seismic Zone (SWSZ). Three large earthquakes have ruptured the surface and caused considerable destruction in the zone: the 1968 Meckering earthquake, the 1970 Calingiri earthquake and the 1979 Cadoux earthquake (figure 1). A sequence of more than 20 000 small earthquakes has also occurred near Burakin since the beginning of 2001.

Geoscience Australia monitors the seismic activity of the SWSZ and because it is near Perth, the Cities Project is developing an earthquake hazard model for the Perth metropolitan area. This model requires knowledge of historical earthquakes and the active tectonics for a broad region centred on Perth.

In December last year, Geoscience Australia held a workshop involving expert Australian seismologists and structural geologists to come up with an appropriate model of seismicity for Western Australia's south-west corner. A round of discussions followed the workshop.

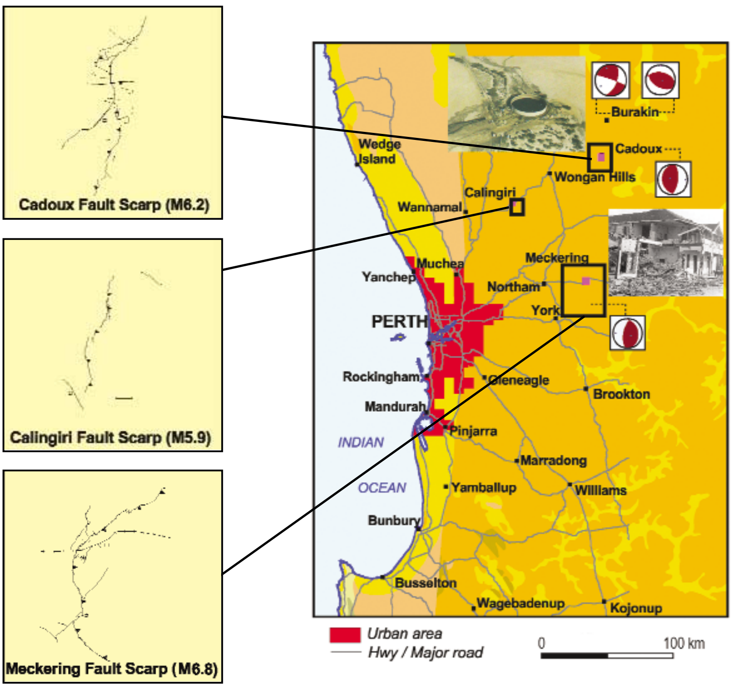


Figure 1. Location of Perth in relation to the three largest earthquakes in the South-west Seismic Zone that ruptured the surface and produced fault scarps. Photograph insets show damage to a water reservoir (1979 Cadoux earthquake) and to Meckering (1968 earthquake). The 'beach balls' illustrate the mechanisms of the most significant earthquakes.

Geoscience Australia's Cities Project provides risk assessments, spatial data, and decision support tools (e.g. figure 1 on page 8). It also works with some local governments that have risk management and community awareness programs, such as the AWARE (All West Australians Reducing Emergencies) program.

Key Western Australia partners include:

- Fire and Emergency Services Authority
- Department for Planning and Infrastructure
- Bureau of Meteorology
- Water and Rivers Commission
- Western Australia Land Information Service
- City of Joondalup
- City of Wanneroo
- Shire of Swan
- Western Power.

Recent terrorist attacks overseas pointed to another use for Cities Project research. Its risk assessment methodology has been adapted to Australia's counter terrorism and critical infrastructure protection activities. Since the Bali terrorist event, Geoscience Australia has joined various government departments and agencies in national counter-terrorist exercises.

The Cities Project is a national project that undertakes applied research to assess the risks to Australian communities from earthquakes, floods, severe winds, landslides, coastal erosion and terrorist bomb blasts. Several multi-hazard and single-hazard risk reports have been published since the project began in 1996. These reports can be downloaded from the web at www.ga.gov.au/urban/projects/20010917_8.jsp:

- Community risk in Cairns, Queensland
- Community risk in Mackay, Queensland
- Community risk in Gladstone, Queensland
- Natural hazards and the risks they pose to south-east Queensland
- Earthquake risk in Newcastle and Lake Macquarie, New South Wales.

For further information phone Trevor Jones on +61 2 6249 9559 or e-mail trevor.jones@ga.gov.au

Seismicity model

The seismic activity in the SWSZ has a number of potential causes. They include zones of weakness or resurgent tectonics, contrasts in lateral density and elastic properties, and high heat flow.

The epicentres for the highest incidences of earthquake are at Meckering and Cadoux (figure 2), where an 's' shaped zone extends from 180 kilometres north-east to 110 kilometres south-east of Perth. Epicentres south of Meckering correlate strongly with structural trends inferred from aeromagnetic data and a general north-north-west trend of the major gravity gradient.

Figure 2 also shows the preferred seismicity model, where:

- Zone 1—the SWSZ includes the Burakin events[1];
- Zone 2— is east of the Darling Fault. The boundaries align with the Darling Fault and regional structural trends[1];
- Yilgarn Zone—extends across the remainder of the Yilgarn Craton;
- Zone 3—is an offshore zone that extends to the continental margin[1]; and
- Background Zone—includes the Perth Basin.

Statistical analyses of historic earthquakes were used to determine each zone's seismic parameters (see figure 2 graph).

The earthquakes generally occur in the top 20 kilometres of the crust and upper mantle, but are more likely to occur in the upper five kilometres. Earthquake mechanisms are typically reverse faulting with the principal stress axis normal to the regional north-north-west structural trend (see 'beach balls' in figure 1). Faults are assumed to dip at 35 degrees east or west of this trend with equal probability.

Once the seismicity model is combined with models of soil and site amplification, earthquake hazard estimates and hazard maps for metropolitan Perth can be generated. These estimates will consider likely damage and replacement costs.

Preliminary results indicate that the new seismicity model produces higher estimates of earthquake hazard for Perth than those in the current Australian Standard (AS1170.4:1993), but more work is needed to refine these estimates.

The most significant factor in the hazard calculations is the rate that ground shaking decays (or attenuates) with distance from the fault. The recordings of the Burakin earthquake sequence will be important in developing an appropriate regional decay or attenuation relation.

For further information phone Cvetan Sinadinovski on +61 2 6249 9525, or e-mail cvetan.sinadinovski@ga.gov.au

[1] Modified from Gaull BA, Michael-Leiba MO & Rynn JM. 1990. Probabilistic earthquake risk maps of Australia. Australian Journal of Earth Sciences; 37:169–187.

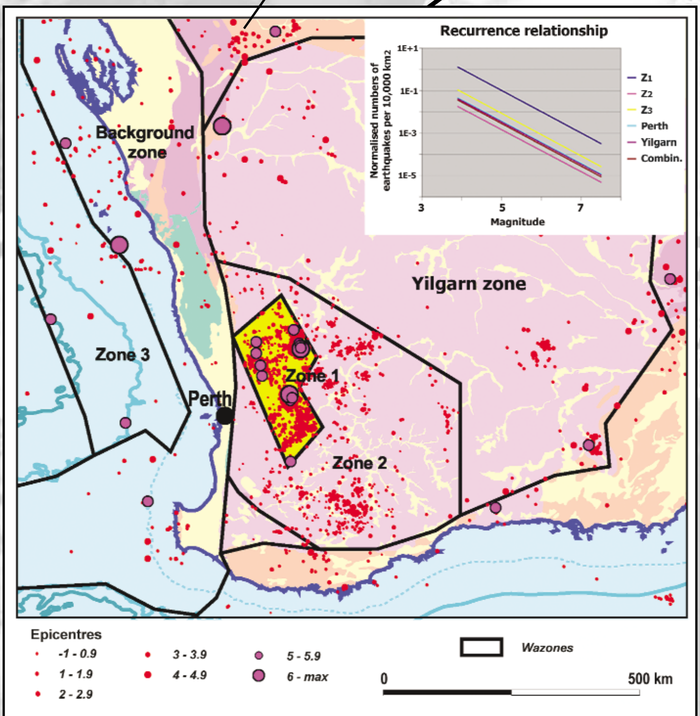
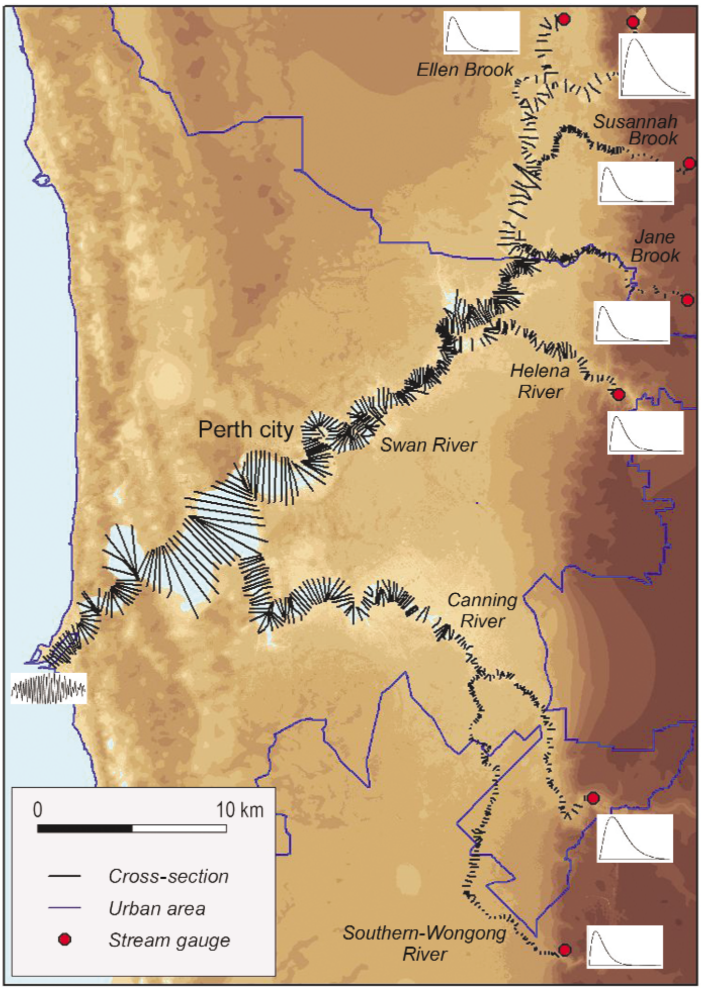


Figure 2. Newly developed earthquake source zones in south-west Western Australia showing earthquake epicentres. The recurrence relationship graph (insert) indicates earthquake frequency at various magnitudes.

Flood risk in depth for *Swan River*

Floods are the most costly natural disaster in Australia. On average, floods cost $314 million annually between 1967 and 1999.[1] In 1974 alone they cost Australia $2.9 billion.



Floods also have a large social cost. Ninety-nine deaths and 1019 recorded injuries in Australia from 1967 to 1999 were flood-related.

The risk of flooding is poorly understood. Incomplete and unreliable information about the extent and frequency of flooding in many parts of Australia puts communities at risk.

Geoscience Australia's Risk Research Group is currently identifying flood risk in Perth, Western Australia.

Flood modelling

Geoscience Australia's flood hazard model uses the United States Army river analysis system (HEC-RAS[2]), a one-dimensional unsteady-flow water surface model, interfaced with geographical information systems (GIS). The model is being applied to the Swan River system in Western Australia (figure 1).

Figure 1. Swan River flood study depicting the location of cross-sections, inflow hydrographs and the tidal influence

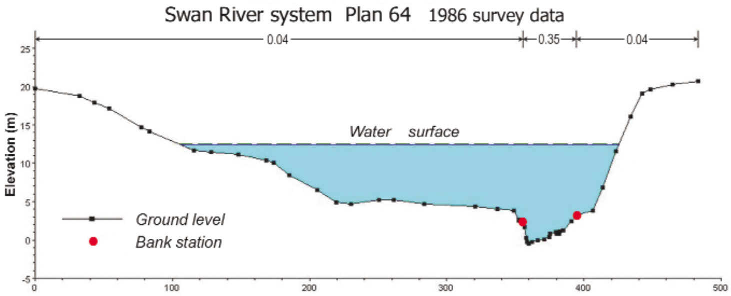


Figure 2. A typical cross-section profile showing a simulated flood

Some of the processes involved in developing the model are listed in table 1. Prior to the Swan River flood study, the data available for Perth were limited to water levels and average velocities at particular locations.

Unsteady-flow models such as HEC-RAS simulate water surface levels, the duration and depth of inundation, and the velocity of flow at any location along a river network.

Risk data

Geoscience Australia is collecting data on floor heights and building construction types in Perth to assess potential building damage for a range of flood events. This data will be used in estimates of Perth's flood risk for small high-frequency events (e.g. one in 10 years) through to extreme flood events of low probability.

HEC-RAS will be used to simulate numerical results at any location and time period. GIS will be used for floodplain visualisation, locating affected buildings, estimating damages, and for communication about flood risk.

Knowing the depth of inundation, flow velocity and duration of inundation are important in assessing flood risk.

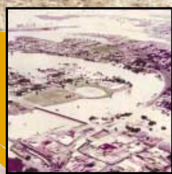
The depth of inundation and corresponding flow velocity are needed to estimate structural damage. Depth and velocity data can also be used to identify potential evacuation routes and to decide whether vehicles or pedestrians can safely traverse an area.

The duration of inundation is important for establishing how long roads will be cut by flood water and houses isolated. It is also used for modelling the duration of disruptions to essential services and business, and the length of time before clean-up can commence.

The Risk Research Group's research is providing relevant authorities with information and tools to focus on flood-risk management rather than only response. Local and state government agencies and private enterprise are involved in the research.

Table 1. Some data required for a flood hazard model

- Cross-section information because cross-sections define the channel and floodplain geometry (see figure 2);
- Estimation of channel and floodplain roughness which influence flow velocity;
- Location of left and right channel banks which delineate the stream channel and floodplain;
- Estimations of inflow into the channel over time for rainfall events with different probabilities. These are modelled throughout the river system to estimate the area inundated by floodwaters, the velocity, and the duration of inundation at any location.



For more information phone Miriam Middelmann on +61 2 6249 9240 or e-mail miriam.middelmann@ga.gov.au

[1] Bureau of Transport Economics. 2001. Economic costs of natural disasters in Australia. Canberra: Bureau of Transport Economics, report 103.

[2] US Army Hydrologic Engineering Centre's River Analysis System (HEC-RAS 3.1)

A blow to SEVERE STORM costs

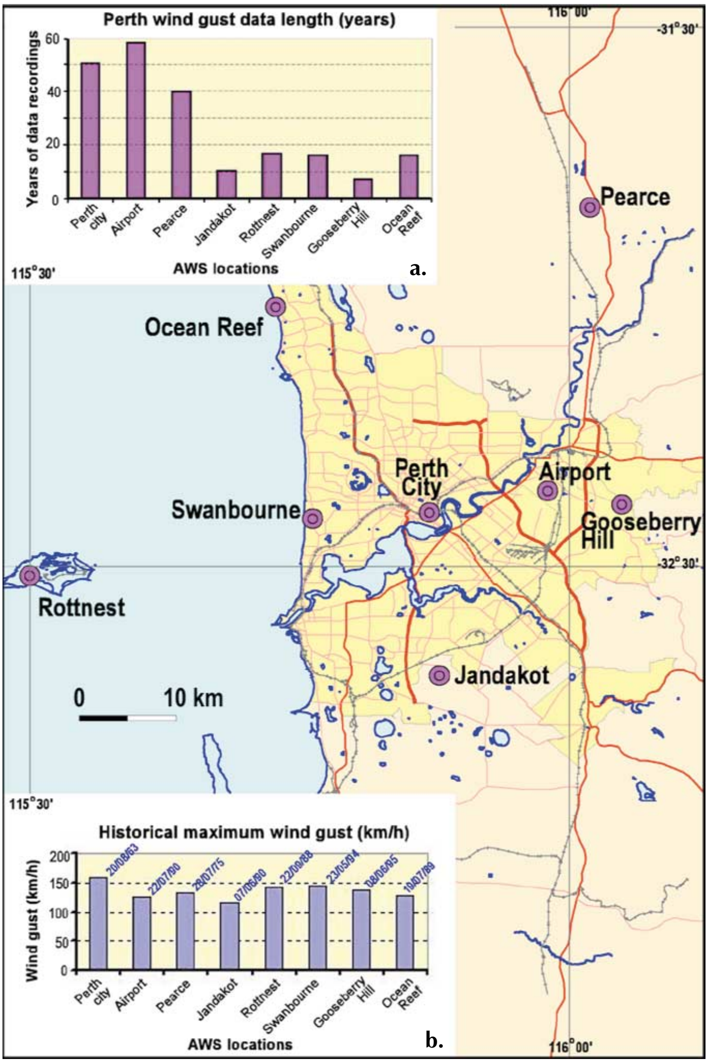


Figure 1. The location of Automatic Weather Stations (AWS) in the Perth region. **Histogram a.** Length of record at each AWS **Histogram b.** Historical maximum wind gust at each AWS

Severe storms cost Australia on average $284 million a year. Just over a quarter, or $9.4 billion of Australia's natural disasters bill for the 32 years from 1967 to 1999 was due to severe storms.[1]

There were 112 severe storms in this period or three to four a year, and each caused more than $10 million damage.

In Western Australia, severe storms are the second most costly hazard after cyclones. They have been quite destructive in the Perth region (table 1 on page 14).

Wind model

Geoscience Australia is using historical wind data, particularly the daily gust (three-second maximum speed) to estimate the probability of future severe storms for metropolitan Perth. Its statistical wind gust model will be used to estimate the speeds and return periods of severe winds.

This information will be added to a number of tools Geoscience Australia is building for city planners and emergency managers aimed at reducing the costs of natural hazards.

The Bureau of Meteorology provided wind gust data for some Automatic Weather Stations (AWS) in the Perth region. Figure 1 shows the stations, their length of record and historical maximum wind gusts.

Strong gusts

The strongest gust, 158 kilometres per hour, was recorded in Perth City in August 1963. The second and third largest gusts were recorded at Swanbourne and Rottnest Island (145 km/h and 143 km/h, respectively).

Date	Location	Description
16 Jun 1954	Dwellingup	Damage in jarrah forest 10 km long and 200 m wide
8 Jun 1968	Naval Base	Destroyed 40 caravans and damaged 24 cottages
9 Sep 1968	Kewdale	30 houses unroofed
8 Jun 1981	South-west coast Metropolitan Perth	Trees and power lines fallen, buildings damaged
28–29 Jun 1983	South-west coast	2 lives lost; fallen trees and power poles; cost >$1 million (1983 dollars)
3 Sep 1983	Scarborough–Mt Lawley	50 houses damaged with some totally destroyed
22 Sep 1988	Perth–Albany	Hundreds of roofs and 20 boats damaged; 100 000 homes lost power; cost $8 million (1991 dollars)
23–24 May 1994	Metropolitan Perth	Most destructive weather event in metropolitan Perth in 30 years; 2 lives lost at sea; houses unroofed; one-third of Perth lost power; beach erosion; foreshore inundated; cost $25 million (1994 dollars)
25 Aug 1999	Fremantle	One person injured; roofs blown off
23 Aug 2001	Kelmscott, Como	90 homes damaged; trees fallen; 10 000 homes lost power

Table 1. Severe wind damage (excluding cyclones and tornados) in the Perth region. *Source: Bureau of Meteorology*

These coastal sites, however, are more exposed than Perth City. Their recordings are for 16 years compared with 58 years at Perth Airport. Stronger, unrecorded gusts therefore may have occurred along the coast.

For each AWS, the frequency distributions of wind speed and direction can be plotted on a 'wind rose' (see figure 2). The wind direction frequencies are 'petals' radiating from a central circle. The wind speed frequencies are petal segments of variable width and length.

Wind direction

At Perth Airport the largest wind frequency (18.4%) comes from the east, and is associated with summer; the second largest comes from the south-west (16.6%). The red petal segment indicates the percentage of storm winds (i.e. those with gusts greater than 88 km/h).

Most storms come from the west (red-coloured histogram in figure 2). These storms typically occur in winter. This feature is clearer when only the occurrences of severe storm winds are shown (i.e. those with gusts greater than 103 km/h—see purple-coloured histogram in figure 2). So although most winds are from the east, severe winds from storms are typically from the westerly quadrant.

Modelling progress

Statistical modelling of severe wind gust at each AWS is under way. The return periods for severe winds will be predicted using the wind gust models.

Potential damage to buildings and infrastructure caused by those return period winds will then be estimated using a wind damage model calibrated with historical storm damage.

For more information phone Xun Guo Lin on +61 2 6249 9153, or e-mail xunguo.lin@ga.gov.au

[1] Bureau of Transport Economics. 2001. Economic costs of natural disasters in Australia. Canberra: Bureau of Transport Economics, report 103.

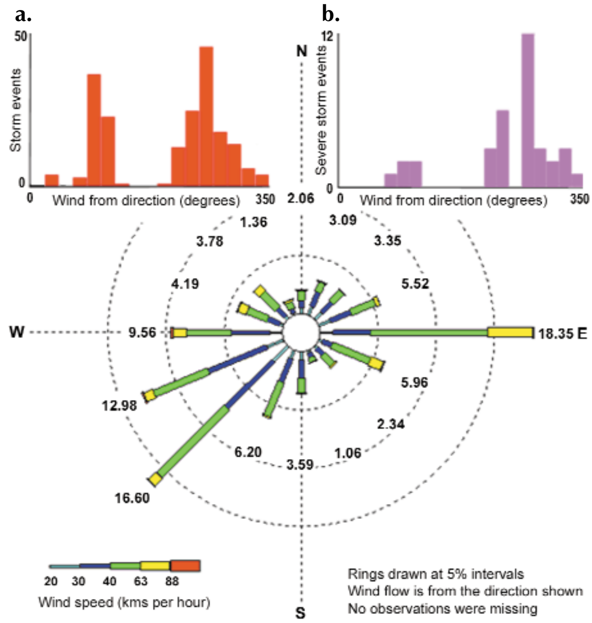


Figure 2. A wind rose plot of 58 years of data from Perth Airport shows the frequency distributions of wind gust and wind direction. **Histogram a.** Storm events from each direction **Histogram b.** Severe storm events from each direction



Australian stations on *nuclear treaty rollcall*

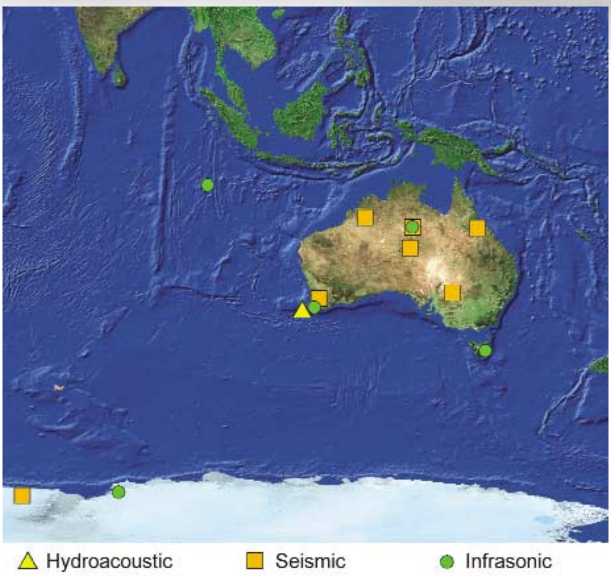


Figure 1. IMS stations in Australia and its territories established to help verify countries are complying with the Comprehensive Nuclear-Test-Ban Treaty

The Comprehensive Nuclear-Test-Ban Treaty (CTBT) bans all kinds of nuclear explosions in the environment—underground, underwater, and in the atmosphere.

The United Nations adopted the treaty on September 10, 1996 and made it open for signature on September 24. Australia signed the treaty in September 1996 and ratified it in July 1998.

The CTBT must be able to independently assess signatories' compliance with the treaty, so a verification regime was established that includes:

- an International Monitoring System (IMS) consisting of a global network of sensors or stations;
- an International Data Centre (IDC) to analyse data from the sensors;
- a Global Communications Infrastructure connecting the IMS and the IDC.

When it is completed, the IMS will have a network of 321 stations in some 90 countries and use four verification technologies:

- seismic (pressure waves in the earth);
- radionuclide (radioactive particles and gases);
- infrasound (sound waves in the atmosphere); and
- hydroacoustic (acoustic waves in the oceans).

Twenty stations will be in Australia and its territories. They will comprise seven seismic stations, seven radionuclide stations, five infrasound stations, and one hydroacoustic station at Cape Leeuwin in Western Australia.

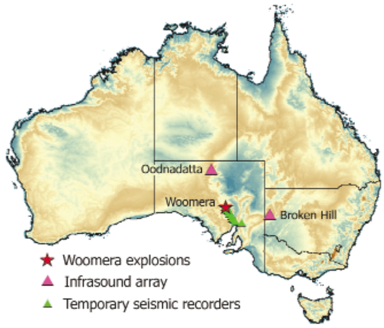
Australia's infrasound stations will be one-twelfth of the total infrasound network. They are in Bucklands in Tasmania and Tennant Creek in the Northern Territory. Three others will be established on Cocos Island in the Indian Ocean, at the Davis station in Antarctica, and one in south-west Western Australia.

Geoscience Australia is responsible for installing, operating and maintaining Australia's hydroacoustic station and most seismic and infrasound stations (figure 1). Its work is vital to monitoring the environment for nuclear explosions.

For more information phone David Jepsen on +61 2 6249 9696 or e-mail david.jepsen@ga.gov.au

WOOMERA blasts ideal for station tests

Geoscience Australia operates a network of seismic and infrasound stations in Australia and Antarctica that monitors earthquakes, and nuclear explosions in the atmosphere and underground.



Recordings from the monitoring stations occasionally need to be calibrated against events with a known location and size.

Large explosions by mining companies are an opportunity to calibrate signals and propagation paths to the stations. But the charges are detonated underground, so mining blasts mainly generate seismic waves in the earth.

A surface explosion that produces both seismic waves and atmospheric sound waves, and is large enough to be recorded far away, is ideal for testing seismic and infrasound station capabilities.

International trial

Two large explosions were detonated above ground during an international explosives trial at Woomera, South Australia, in September–October last year.

The first explosion comprised 1620 artillery shells, equivalent to 27 tonnes of explosive, stacked inside a concrete and earth building.

In the second explosion, 300 artillery shells, or five tonnes of explosive, were placed in a steel shipping-container surrounded by earth and water barriers. On both occasions special buildings were constructed around the site to test the effect on the structures.

The trial was part of a series of explosions conducted for defence research by Britain's Ministry of Defence and Australia's Department of Defence. The United States, Netherlands, Norway and Singapore also participated.

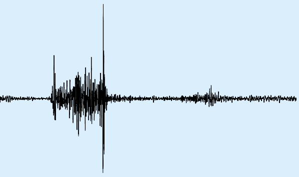
Borrowed recorders

Geoscience Australia borrowed infrasound recorders from the Geological Survey of Canada to record calibration data from the explosions. Recording sites were located near Oodnadatta and at Broken Hill, 500 kilometres north and 500 kilometres east of the test site, respectively (figure 1).

Sound waves from the explosions arrived at each station following a number of preferred propagation paths (phases) through the atmosphere.

▲ **Figure 1 (map).** Location of infrasound and seismic stations

◀ **Photograph.** The 27-tonne explosion was detonated above ground during an international explosives trial at Woomera, South Australia late last year. Photo courtesy of the Department of Defence (DSTO)



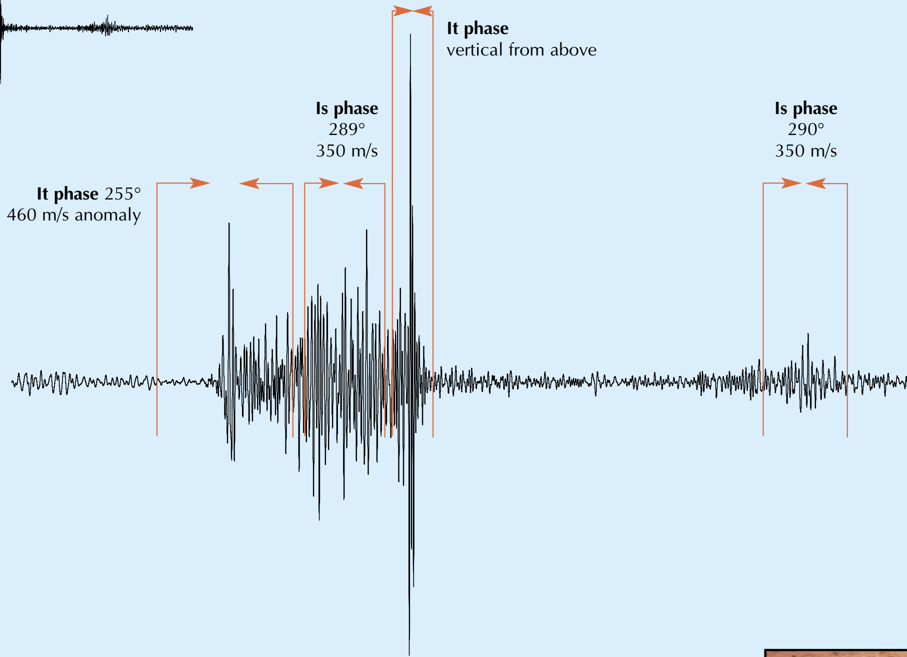
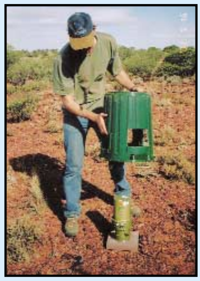


Figure 2. Infrasound record from Broken Hill showing the two major phases that characterise the signal



Setting up an infrasound recorder

The two major phases that characterise the signal are the Stratospheric (Is) and Thermospheric (It) phases.

The Is phase refracts in the stratosphere and turns at an altitude of about 45 kilometres, executing a ground-based bounce every 250 kilometres. The It phase refracts in the thermosphere at an altitude of about 120 kilometres, bouncing on the ground at approximately 500-kilometre intervals. These phases can be roughly discriminated because the steeper signals have the higher apparent velocity (figure 2).

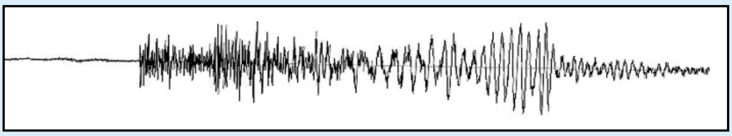


Figure 3. Seismic signal 32 kilometres from the explosion

Unexpected results

The recorded data show some unusual results, particularly at the Broken Hill station. As well as a weak Is phase arriving as expected, significant scattered signals were recorded (figure 2).

Arrival times are significantly earlier than expected, and the signals are characterised by measured azimuths that depart significantly from the expected great circle value.

This effect is probably topographic because the Flinders Ranges are between the source and receiver. Similar results were recorded for both explosions at the Broken Hill station.

By analysing the characteristics of these acoustic signals, Geoscience Australia can better interpret data from its network of permanent infrasound stations.

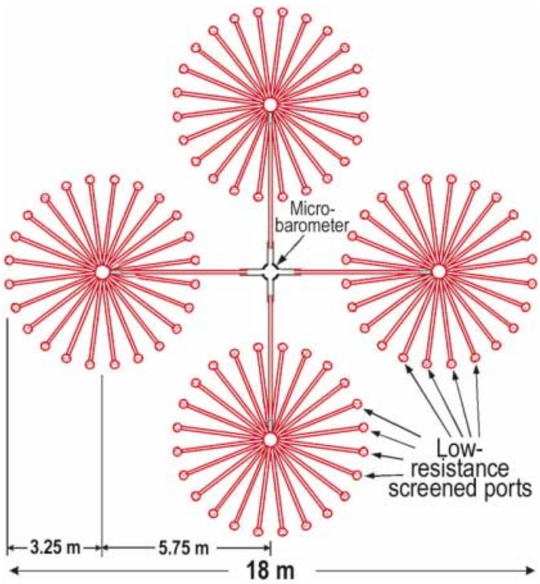
Temporary stations

Temporary seismic stations were deployed between Woomera and Peterborough to record the explosions (figures 1 & 3). From these recordings the velocities of seismic waves in the region can be measured to help refine the locations of earthquakes recorded by permanent stations.

The amount of ground shaking to expect from earthquakes in the region can be estimated by measuring seismic wave variations with distance from the explosion.

For more information phone Clive Collins on +61 2 6249 9544 or e-mail clive.collins@ga.gov.au

Sensitive arrangements for listening in



A nuclear explosion detonated in the atmosphere produces sound waves (atmospheric pressure variations) over a range of frequencies. Higher frequencies are rapidly absorbed with distance. Very low-frequency energy is not as quickly absorbed and can be detected thousands of kilometres away.

Infrasound stations detect low-frequency sound waves (signals from 0.02 to 4 hertz) from explosions detonated in the atmosphere or at shallow depths in the oceans. The human ear responds to sounds in the frequency of 20 to 20 000 hertz.

An infrasound station consists of a number of very sensitive microbarometers (figure 1). To increase station sensitivity, each microbarometer is connected to several radiating pipes with small holes (ports) along the length. This arrangement, commonly called a space filter, averages and largely cancels out pressure variations localised over an area smaller than the filter (such as wind-generated turbulence), leaving the signal largely intact.

Tuned into ocean sounds via whale channel

About 1000 metres deep in the oceans there is a channel where the speed of sound is at a minimum and sound waves can travel hundreds of kilometres with little loss. This layer of water is called the SOFAR channel.

Whales seem to be in tune with the properties of this channel. Humpback whales are thought to communicate with each other at great distances by diving to the channel to 'sing'.

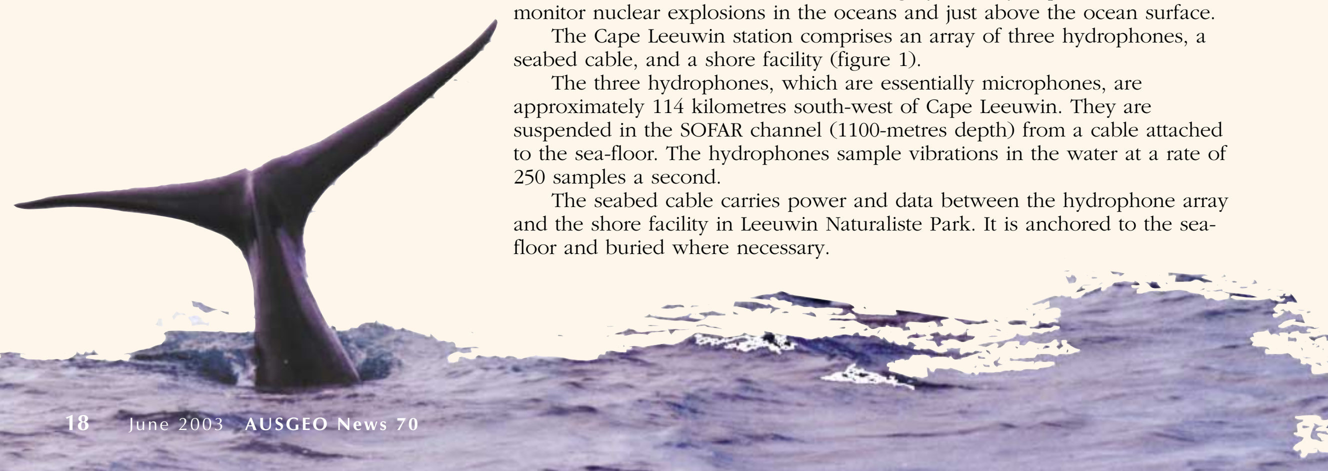
Hydroacoustic stations also use this phenomenon by suspending hydrophones in the channel to record distant signals. For example, a few-kilogram charge exploded in the SOFAR channel off South Africa would be clearly recorded at the Cape Leeuwin hydroacoustic station in Western Australia.

Only a few hydroacoustic stations are needed to monitor the world's oceans. The Cape Leeuwin station monitors the Indian Ocean, the Great Southern Ocean, and the southern parts of the Pacific and Atlantic oceans. It is one of six IMS (International Monitoring System) hydrophone stations that monitor nuclear explosions in the oceans and just above the ocean surface.

The Cape Leeuwin station comprises an array of three hydrophones, a seabed cable, and a shore facility (figure 1).

The three hydrophones, which are essentially microphones, are approximately 114 kilometres south-west of Cape Leeuwin. They are suspended in the SOFAR channel (1100-metres depth) from a cable attached to the sea-floor. The hydrophones sample vibrations in the water at a rate of 250 samples a second.

The seabed cable carries power and data between the hydrophone array and the shore facility in Leeuwin Naturaliste Park. It is anchored to the sea-floor and buried where necessary.



The maximum dimension of the space filter is limited by the frequency range of the signals of interest and the speed of sound in air. For a normal IMS station the space filter's diameter is a maximum of 18 metres. The higher frequency signals begin to cancel out if it is larger.

A typical IMS infrasound station comprises eight microbarometer sensors and associated space filters. The exact layout of the station is not critical, and individual elements can be set up to take advantage of local conditions such as topography or patches of forest.

By using each sensor as an element of a larger array, the signal-to-noise ratio is increased. With multiple sensors, the signal's direction can be determined by the different arrival times of sound waves at the various sensors.

Data from infrasound stations could have a number of other civil and scientific applications such as aviation safety and weather monitoring. They include detection of volcanic explosions and aircraft wind shear, early warnings of tornado touchdowns, detection of meteors in Earth's atmosphere, and storm monitoring and tracking.

Geoscience Australia will operate four IMS infrasound stations. The first, at Bucklands in Tasmania, began transmitting data to the IDC (International Data Centre) in March this year.

For more information phone David Jepsen on +61 2 6249 9696 or e-mail david.jepsen@ga.gov.au

Figure 1. The design of microbarometer and associated pipe array and ports for the Australian infrasound stations

The Bucklands infrasound station was completed in March 2003. **Top:** Geoscience Australia's Shane Nancarrow stands inside the vault that will contain the microbarometer and recording equipment. Air inlet ports are in the foreground. Also pictured (l to r) are Jack Pittar, David Brown, David Jepsen and David Pownall.

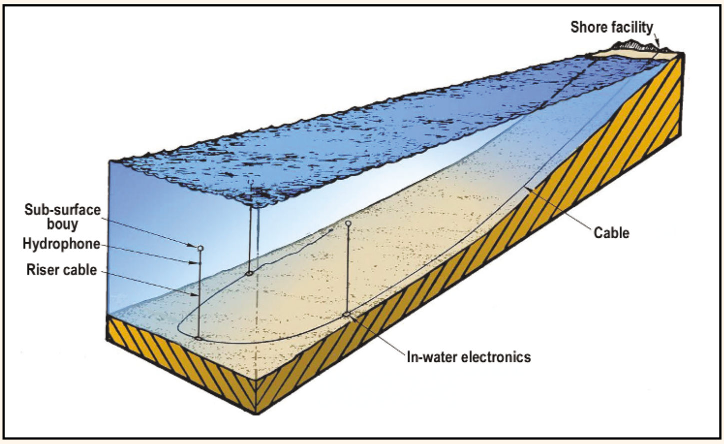
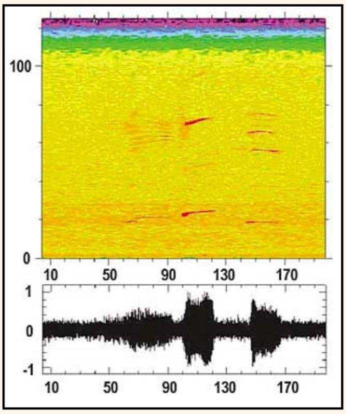


Figure 1. Components of the Cape Leeuwin hydroacoustic station

Figure 2. Hydrophones record the complex tones in a pygmy blue whale call (bottom of the figure). The upper part of the figure is a spectrogram of the call.



The shore facility powers the hydrophone array, records and reformats the data, and then transmits the data via satellite to the IDC in Vienna and by landline to Geoscience Australia in Canberra. The station has been transmitting data since September 2001 to Vienna and Canberra.

At the IDC, the data are combined and processed with other IMS station data, analysed, and if there is evidence of an event, relayed to the Comprehensive Nuclear-Test-Ban Treaty signatories.

Cape Leeuwin station also observes signals from non-explosive sources, which could be valuable for other civil and scientific applications. They include continental and oceanic earthquakes, mid-oceanic volcanic activity, underwater landslides, whales (figure 2), shipping noise, ocean swell and offshore exploration surveys.

Research into ocean processes and marine life, and monitoring underwater volcanoes and ice shelf break-up are a few potential applications for Cape Leeuwin data.

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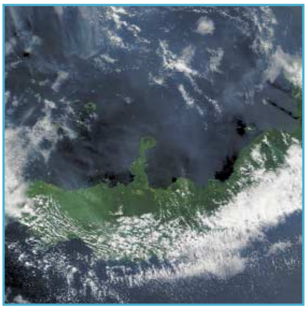
PAGO'S *surprise* performance

Without warning, Pago volcano in Papua New Guinea erupted on August 5 last year, after being dormant for nearly 70 years. There were no seismometers or tiltmeters on the volcano to record activity and suggest an eruption was imminent.

South-east trade winds blew thick clouds of volcanic smoke and ash towards the north-west, closing West New Britain's main airport at Hoskins, and threatening the oil-palm industry.

Thousands of people self-evacuated from surrounding villages to care centres in the Kimbe area, 50 kilometres east of Pago.



Terra-MODIS image 02.09.02

TSUNAMIS IN THE SOUTH PACIFIC

Research towards preparedness & mitigation

25 & 26 September, 2003

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Plus an optional one-day field trip

This two-day international workshop focuses on research related to understanding tsunami hazards and developing tsunami warning and mitigation measures. Participants will:

- review tsunami observations and preparedness in the south-west and central Pacific;
- analyse regional features for tsunami generation, propagation and impact;
- exchange experiences in developing mitigation measures; and
- formulate recommendations for tsunami disaster reduction.

The field trip takes participants to the coast to view dramatic landscape changes caused by tsunamigenic earthquakes such as the M8+ event in 1855.

If you are interested in this workshop contact Gaye Downes tel. +64 4 570 4827, e-mail tsunami_conference_nz2003@gns.cri.nz

Eruptive history

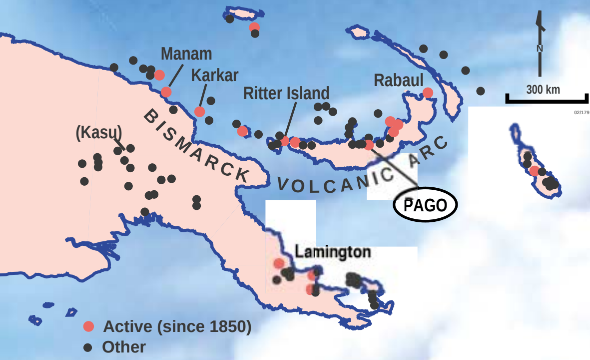
Pago is a 250-metre-high cone, within the summit of Witori volcano. Its last eruptions in 1928–33 were minor. But a larger eruption in 1911–18 produced ash fall, a scoria cone, and dacitic lava flows that may still have been active in 1923.

Witori is a caldera or collapsed crater about seven kilometres wide, formed by an enormous, explosive eruption more than 3000 years ago. Krakatoa, which erupted in 1883, was a caldera volcano.

Some volcanologists were concerned that Pago's eruption last August could develop into another major, caldera-forming event.

Uncanny

By coincidence, Geoscience Australia's Trevor Dalziel had arrived at Rabaul Volcanological Observatory (RVO) just hours before Pago's eruption.



awakens dormant fears

He was about to install a seismograph on Pago volcano for the first time. It would be included in PNG's national remote-volcanoes network.

The network was established after the disastrous 1994 volcanic eruption at Rabaul, with AusAID funding (the Australian Agency for International Development). The Pago installation was a joint Geoscience Australia–United States Geological Survey (USGS) project, co-funded by AusAID and the US Office of Foreign Disaster Assistance.

But Pago erupted before Dalziel could travel to the volcano.

International help

Volcanological teams from Japan and the United States went to West New Britain to assist PNG authorities and particularly the RVO to manage the crisis and monitor the eruption.

They established seismographs and satellite GPS stations (for measuring ground deformation) within Witori caldera. This is an uninhabited part of New Britain where the terrain is extremely rough and access is difficult.

Signals from the instruments were relayed electronically via a repeater station on nearby Mount Oto (an extinct volcano) to the Kimbe Volcano Observatory.

Dalziel and a group of RVO technicians then installed their seismograph in the caldera, and used the Mount Oto and Kimbe links to send signals directly to RVO headquarters in Rabaul. RVO could now monitor the progress of the Pago eruption scientifically.

Satellite imagery of the volcano provided additional information, which aviation authorities and others used for tracking ash clouds and detecting thermal emissions from Pago.

Current behaviour

Pago's activity is like the 1911–18 eruption when lava was extruded for several years.

Since August, dacitic lava has been flowing from a vent low on the north-eastern side of the cone. This was one of a string of vents forming a fissure on the volcano's northern flank.

The flow moved northwards, then eastwards along the foot of the caldera wall for over two kilometres, until a ridge blocked its progress. The lava then ponded and gained height.

A southern lava lobe formed from the same vent, but it has not grown as much as the main lobe. The lava flow is confined to the uninhabited caldera and is no threat to communities.

There have been no more explosive eruptions like those in August 2002. People have returned to their villages.

Hoskins airport remains closed, but the disused airstrip at Talasea to the north of Kimbe has been upgraded for commercial aircraft.

Nevertheless RVO is watching for changes in the erupted magmas, in particular for more gas-rich and explosive magmas.

Trevor Dalziel installing a seismograph

Ongoing role

Geoscience Australia is assisting with the ongoing monitoring of the Pago eruption as part of an international response and relief program, because volcanic eruptions continue to threaten life and property in PNG.

Scientific links between Geoscience Australia and RVO are maintained through an AusAID-funded program.

These links are historical, as Geoscience Australia—then the Bureau of Minerals Resources (BMR)—re-established RVO in 1950 after the Second World War and ran the observatory until PNG independence in 1975. A former BMR director established the original RVO in 1940 in response to the 1937 Rabaul eruption, which killed more than 500 people.

For more information phone Wally Johnson on +61 2 6249 9377 or e-mail wally.johnson@ga.gov.au

Lightning response tracks bushfire spread

January 10 was hot and very dry. El Niño was influencing conditions and much of Australia was in drought.

Forest floors in the Australian Alps and nearby national parks were tinder dry and littered with leaves. Lightning didn't bring rain. But it started fires in the parks.

If fires spread, at very short notice fire fighters and emergency managers would need maps of threatened areas and satellite images of fire perimeters and movement.

Geoscience Australia's National Mapping Division staff was ready when requests came for images of forested areas of southern New South Wales, northern Victoria and the Australian Capital Territory.

At 5.10 p.m. on January 17, the Ovens Fire Control Centre near Wangaratta, Victoria, requested 202 maps. The Control Centre had its maps by 11.30 that night.

High winds fanned the fires and by January 19, hundreds of livestock and native animals were burnt, thousands of acres of land scorched, and more than 900 firefighters were battling fires. In Canberra over 400 suburban homes were destroyed or fire damaged, and four people were dead.

Geoscience Australia had processed and couriered more than 3000 maps directly to firefighters. Many other maps and satellite images were delivered to politicians, media and the public.

Satellite images

At receiving stations near Alice Springs and Hobart, Geoscience Australia captures data from sensors on passing satellites. It processes the data into images of the Australian region.

MODIS and Landsat data provided big pictures of the extent and direction of January's fires as they swept across south-eastern Australia (see figures 1 & 2a–b). Both types of data were important because their satellites have different orbits and provide different details.

Although the MODIS resolution has less detail than Landsat, every day its satellite's path covers almost the entire surface of the Earth and scans Australia three or four times, which makes it a good tool for updating the progress of fires.

Fire Control Centres used the satellite images to locate areas of greatest concern, map fire perimeters and burn scars, and to allocate resources. Politicians and media used the images to keep the public informed.

Post-fire maps

After the fires, Geoscience Australia created a number of special, small-scale maps for individual clients to assess the extent and likely damage, for example, to businesses and government property.

These maps combined all kinds of information such as topographic data, ACC (Area Consultative Committee) boundaries, infrastructure and satellite imagery (figure 3).

For more information phone Ian O'Donnell on +61 2 6201 4100 or e-mail ianodonnell@auslig.gov.au

Fires engulf satellite tracking station

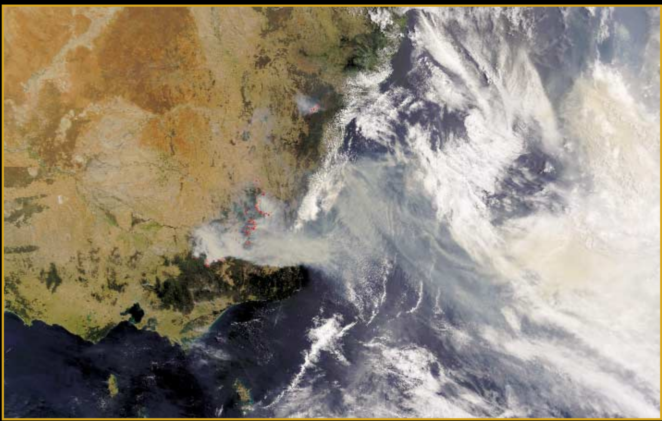
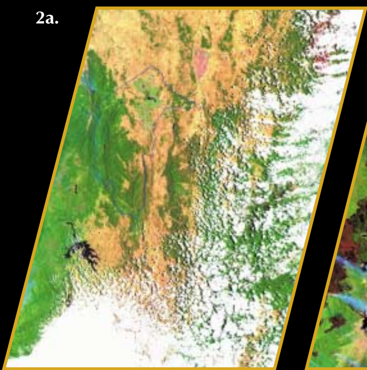
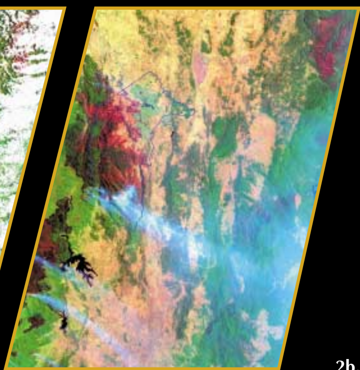


Figure 1. Canberra is covered in smoke in this MODIS (moderate resolution imaging spectroradiometer) image from NASA's Terra satellite on January 19 this year. The bushfires are marked with red dots.

2a.





2b.

Figure 2a. Small smoke plumes in southern New South Wales visible in the Landsat image acquired on January 10 hint at what is to come.

Figure 2b. The Landsat image acquired on January 26 shows large burnt areas of national parks and the Australian Capital Territory. Scarring from the December bushfires south-west of Sydney is also visible. The bushfire smoke is blue in colour, healthy vegetation is green, and the burnt areas are dark red–brown in colour.

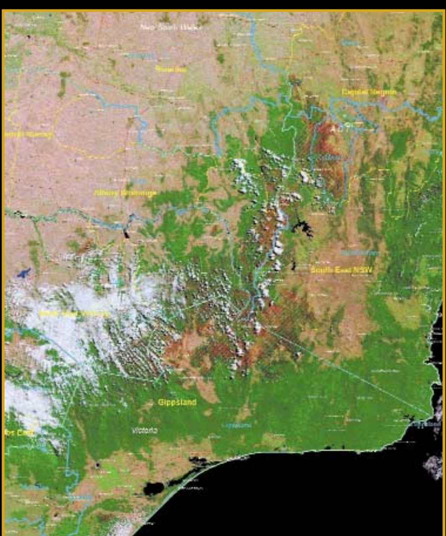


Figure 3. One of a number of maps produced specifically for the Office of Small Business (Department of Industry, Tourism and Resources) that combined state and territory borders, fire scar areas, ACC (Area Consultative Committee) boundaries and MODIS imagery. It shows the extent of fire damage to the Australian Capital Territory as at March 2003.

The Mount Stromlo Satellite Laser Ranging (SLR) station was destroyed in the Canberra firestorms on January 18. There was no time to remove multimillion-dollar equipment as fierce fires swept through surrounding forests. Nothing could be salvaged from the debris.

Mount Stromlo had the most advanced satellite tracking equipment in the world. Its tracking data were copied daily off site, so no records were lost.

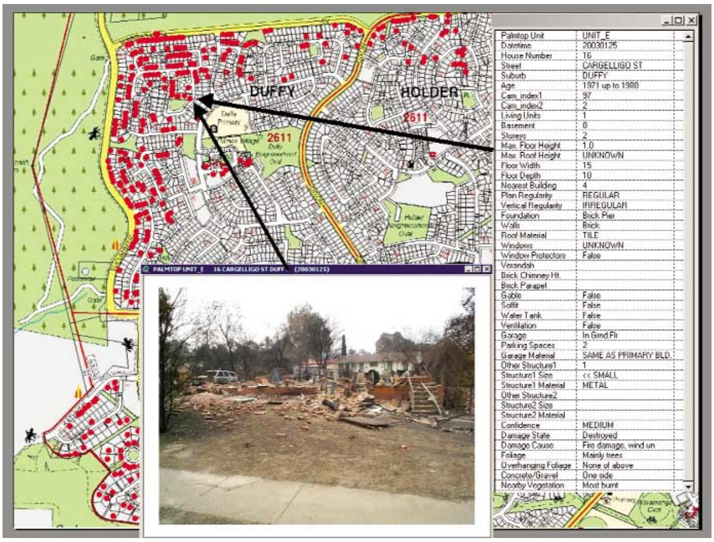
Mount Stromlo is one of two SLR stations in Australia that determine the precise position and orbit of satellites. The other station is at Yarragadee in Western Australia. There are only four stations in the Southern Hemisphere.

SLR measures distances between a laser telescope and satellites. Short pulses of laser light are fired at the corner of a cube prism on a passing satellite. Based on the speed of light, the time taken for the light to reflect from the prism and return to the Earth is equivalent to the distance of the round trip. Mount Stromlo was achieving sub-centimetre accuracy in these measurements.

Global Positioning Systems (GPS) were also destroyed in the Mount Stromlo fire. Because Australia has a large GPS network, other stations such as Tidbinbilla near Canberra, Townsville and Hobart are processing data normally sent to Mount Stromlo.

Geoscience Australia is currently negotiating the rebuilding of Mount Stromlo facilities. The new facilities should be completed by the year's end.

Crucial data captured **from firestorm remains**



▲ **Figure 1.** More than 1500 digital photos were taken and linked to the GIS information

An ill wind whipped up Canberra's January 18 firestorm and even though it was very destructive, it might eventually have blown some good.

In the aftermath, Geoscience Australia had a unique opportunity to collect crucial data about fire behaviour and building damage. This information is invaluable for accurate modelling of possible future events and their consequences, and for developing emergency management procedures.

Using GPS (global positioning satellite-system) units, digital cameras, and palm-top computers with ArcPad GIS software, Geoscience Australia's Cities Project staff recorded details about 431 suburban properties, where the primary residence was damaged by fire and/or wind (table 1). More than 1500 digital photos were also taken and linked to the GIS information (figure 1).

The large percentage of homes that were completely destroyed (91%) compared with those less damaged (9%) indicates the rapid movement and ferocity of the firestorm. Once buildings were ignited, most were completely destroyed.

Extreme winds ahead of the fire front in south-western Canberra uprooted trees, downed powerlines, blew in house windows, stripped roof tiles and even lodged pot plants in roofs. The fierce winds alone severely damaged five per cent of houses.

Cities Project data are presently being integrated with other scientific data such as the CSIRO's data on fire spread and intensity. This research will help emergency managers, planners and engineers to develop appropriate policies and regulations for future fires. It will allow other cities to learn from Canberra's experience.

Table 1. Canberra suburbs and number of homes damaged in the January firestorm

Damage state	Chapman	Curtin	Duffy	Giralang	Holder	Kambah	Lyons	Rivett	Torrens	Weston
Destroyed	77	3	221	1	35	28	4	13	2	6
Heavy damage	2	1	2		1	4				
Medium damage	3		1	1						
Light damage	11		6			2				
Superficial	3		2			2				
Sub-total	96	4	232	2	36	36	4	13	2	6
									Total	**431**

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