Criterion 4

Conservation and maintenance of soil and water resources

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Royal National Park and Hacking River from Bungoona Lookout.

Criterion 4 Conservation and maintenance of soil and water resources

This criterion is concerned with two of the fundamental components of a forest ecosystem: soil and water. Forests are important for soil conservation because they contribute directly to soil production and maintenance, and prevent or reduce soil erosion. Forested catchments also provide and protect high-quality water supplies for a range of uses.

This criterion has five indicators, the first of which is relevant to both soil and water. The second and third indicators address soil, while the remaining two indicators focus on water.

Management of forest for protective functions

Most areas of forest in Australia are managed for multiple purposes, so the identification of forest areas managed primarily to protect soil or water is not straightforward. In Indicator 4.1a, this area is calculated from the area of forest in public formal and informal nature conservation reserves, the area of multiple-use public forest that is protected by prescription (such as steep slopes, erodible soil types and riparian – streamside – zones), and the area of forest in catchments managed specifically for water supply.

Disturbances that can directly affect soil and water in forested areas include road construction and maintenance, wood harvesting, fire, grazing, recreation, and the activities of feral animals. The regulatory systems in place to control and limit the effects of such disturbances are described and assessed in this criterion.

In catchments where forests have been removed or degraded, protective functions can be improved by vegetation rehabilitation and reforestation. Tree-planting is therefore undertaken by government agencies, conservation organisations and community groups across Australia to protect riparian zones, counter rising water tables and salinity, provide wildlife corridors, and prevent or minimise soil erosion.

Management of risks to forest soils

The regulatory systems in place to manage the risks of soil erosion and of damage to soil physical properties in forests are described and assessed in Indicators 4.1b and 4.1c, respectively. These systems recognise that appropriate management of soils is fundamental to sustainable forest management. Minimising soil erosion protects soil and water values in forested areas, and is critical to maintaining many other forest values.

Soil erosion on forested lands can be minimised through careful planning and management of road crossings and forestry operations, with detailed prescriptions depending on the nature of particular forest soils and the activities being undertaken.

Indicator 4.1c addresses degradation of the soil physical properties (such as soil structure, density, texture, permeability, and water-holding capacity) that can affect seed germination and the growth and survival of trees, and that can lead to increased water runoff and soil erosion. It is important that forest management does not result in permanent adverse changes to soil physical properties.

Management of the risk to water quality and quantity

Indicators 4.1d and 4.1e address management of the risk to the quantity and quality, respectively, of water produced from forested catchments. In general, forested catchments provide a lower risk to water quantity and quality, and maintain water quantity and quality values, better than catchments carrying other, non-forest land uses. In Australia, large areas of forested land are used to provide reliable and clean supplies of water for human consumption, as well as for agricultural irrigation and industrial uses.

The quantity of water available in streams and rivers flowing from forested catchments depends, among other things, on the quantity of rainfall, the volume of water used by forest vegetation or otherwise evaporated, and the volume that enters groundwater systems. The amount of water used by a forest stand in turn depends on its age, density, species mix and growth rate. Major fire events influence water yields by changing the canopy cover and age-class structure of native forest, and changes in streamflow can last for decades after a severe fire. Management practices likely to increase or decrease water yields in forested catchments include the timing, scale and location of wood harvesting; the thinning of regrowth forest; management of planned and unplanned fires; and control of woody weeds. Establishing plantations on previously cleared land can also affect water yield from this land. The level of understanding of these processes, and research into improving that understanding, are assessed in Indicator 4.1d.

Forested catchments are highly valued as sources of drinking water because forest vegetation, soil and litter serve as natural filters, and the quality of water flowing from such catchments is therefore usually higher than from non-forested catchments. Natural disturbances such as bushfire can reduce water quality, for example through increased run-off resulting in increased erosion. Construction and maintenance of forest roads and tracks can also have adverse impacts, including through increased movement of sediment into streams and water bodies. In addition, water quality can be adversely affected by fertiliser and herbicide residues from runoff and spray drift. Indicator 4.1e therefore also assesses compliance with the protective measures employed routinely in Australian forests to protect water quality, as well as research into the effects of disturbance in forested catchments.

This icon indicates data, maps or graphics from *Australia's State of the Forests Report 2018* that are available for electronic download. Data used in figures and tables in this criterion are available via www.doi.org/10.25814/5bda9272d76d7.

Indicator 4.1a

Area of forest managed primarily for protective functions

Rationale

The area of forest land where priority is given to protecting soil and hydrological functions provides an indication of the emphasis being placed by society on the conservation of these values. This indicator includes areas managed to protect soil and water by excluding incompatible activities.

Key points

- The area of Australia's public forest managed primarily for protection of soil and water values is 36.6 million hectares (27% of Australia's total forest area).
  - This area includes formal nature conservation reserves, informal reserves in multiple-use public forests, forests protected by prescription (such as steep slopes, erodible soil types and riparian – streamside – zones where harvesting and road construction are not permitted), and forested catchments managed specifically for water supply.
  - The 27% of total forest area that is public forest managed primarily for protection of soil and water values is an increase from the 24% reported in SOFR 2013.
- A total of 1.3 million hectares of forested land is recorded as being managed specifically to supply water for human or industrial use.
  - Current data on this parameter are not available for all jurisdictions.
  - In catchments managed specifically for water supply, jurisdictions either do not allow any human activities to occur, or approve only limited activities. As far as possible, natural disturbances such as fire are also managed.
- National-level programs and other initiatives continue to encourage re-establishment, restoration and maintenance of native vegetation, including forests, for protective functions.

Forests are vital for soil conservation, preventing soil erosion, protecting water supplies and maintaining other ecosystem functions. States and territories have measures in place to recognise and safeguard these functions.

Area of public forest managed for protective functions in regards to soil and water

Identifying forest managed primarily for protective functions in regards to soil or water is not always straightforward. In most states and territories, forests in public nature conservation reserves may be considered as 'managed primarily for protective functions'. However, protection of soil and water is one of several forest management objectives in multiple-use public forests.

The area of forest reported in this indicator as managed primarily for protective functions in regards to soil and water is the area of public forest from which wood harvesting is excluded. This area therefore includes nature conservation reserves, and also those areas of multiple-use public forests from which wood harvesting is excluded such as steep slopes, erosion-prone soils and areas close to streams, as well as the relatively small area of forested land managed specifically for water supply. The notes for Table 4.1 give details of the areas included for each jurisdiction. There are insufficient data to estimate the area of forest on private land managed primarily for protective functions.

The area of public forest managed primarily for protection of soil and water values, across all tenures, totalled 36.6 million hectares in 2016 (Table 4.1). This is 27% of the total forest area in Australia, an increase from the 24% of total forest reported in SOFR 2013.

The increase in the area of public land managed primarily for protection of soil and water values compared to that reported in SOFR 2013 has resulted from the increase in Australia's reported forest area (see Indicator 1.1a), from the declaration of new nature conservation reserves, and from the establishment of new formal and informal reserves on multiple-use public forest. The increases in the Northern Territory, Western Australia, South Australia and the Australian Capital Territory are mostly due to the increase in Australia's reported forest area. In Tasmania and Queensland, the increases are due to changes in reported tenure and to additional reserves, including gazettal in Queensland of new Indigenous Protected Areas. The slight decrease in New South Wales is due to areas mapped as forest in SOFR 2013 being reclassified as non-forest in SOFR 2018 (see Indicator 1.1a).

Management of forests for protective functions in regards to soil and water

Some of the types of disturbance that can directly affect soil and water assets in forested areas are road and track construction and maintenance, infrastructure development, wood harvesting, fire, grazing, recreational activities, and disturbance by feral animals.

Codes of forest practice, and licences issued by regulatory authorities, set out precautionary and mitigation measures to be undertaken in riparian zones near waterways, in areas vulnerable to erosion and slope instability, and in water catchments more generally to minimise the impacts of disturbance, particularly from wood harvesting and road and track construction or maintenance. Specific legally and non-legally binding instruments exist in all states and territories to control and limit forest disturbances in designated water supply catchments. A summary of legal and non-legal instruments that are in place to protect forest areas is given in Indicator 7.1a.

In New South Wales, Environmental Protection Licences (EPLs) and codes of practice require that soil, water catchment, cultural and landscape values are protected by careful planning, location, construction and maintenance of roads and tracks, and regulation of their use. Areas of New South Wales state forests and private plantations are assessed for soil erosion hazard before wood harvesting commences, as part of the harvest planning process. An EPL is required for specified forestry activities in areas of state forest that come under an Integrated Forestry Operations Approval (IFOA); and an IFOA is required for any forestry operation on state forests or other Crown timber lands, including in the western part of the state not covered by a Regional Forest Agreement. The New South Wales Government has also implemented a Private Native Forestry Code of Practice that sets minimum operating standards for wood harvesting (EPA 2013b), including coverage of soil and water values. The *National Parks and Wildlife Regulation 2009* and other regulatory instruments provide protection from disturbance activities such as road construction or bushfire hazard reduction in conservation reserves.

In South Australia, various pieces of legislation and other instruments contribute to appropriate forest management to protect soil and water resources. These include the *Natural Resources Management (Commercial Forests) Amendment Act 2011*, the *Environment Protection Act 1993* (which includes special protection provisions for water quality in water protection areas), the eight regional Natural Resource Management Plans, the State Natural Resources Management Plan 2012–2017, and the *Guidelines for Plantation Forestry in South Australia 2009*.

In Victoria, many catchments supplying water for domestic, irrigation or other purposes, including some catchments containing forest, are protected under the *Catchment and Land Protection Act 1994*. This assists planners and those managing land disturbance or development activities to determine the suitability of proposed activities within these catchment areas. Once a catchment is declared, approvals for activities conducted under other statutes and statutory planning schemes must be referred to the responsible land management authority for approval. Victoria's Catchment

Table 4.1: Area of public forest managed primarily for protective functions including protection of soil and water values

	ACT[a]	NSW[b]	NT[a]	Qld[a]	SA[a]	Tas.	Vic.[b]	WA[b]	Australia	
	Area ('000 hectares)								Area ('000 hectares)	Proportion of total forest[c]
2016	120	6,111	5,847	8,889	2,614	2,086[a]	4,294	6,613	**36,573**	**27.3%**
2011	114	6,119	3,781	6,510	2,112	1,828[d]	4,318	5,026	**29,808**	**23.9%**

[a] Area figures for ACT, NT, Queensland and South Australia, and area figures for Tasmania for 2016, are the areas of forest in Collaborative Australian Protected Area Database (CAPAD), International Union for Conservation of Nature (IUCN) categories I–VI (see Indicator 1.1c), and do not include forests on informal reserves in multiple-use public forests.

[b] Area figures for New South Wales, Victoria and Western Australia are the areas of native forest in formal and informal reserves, and forests protected by prescription in multiple-use public forests (see Indicator 1.1c).

[c] Proportions for 2016 are based on total area of forest reported in SOFR 2018 (134.0 million hectares; see Indicator 1.1a). Proportions for 2011 were based on total area of forest reported in SOFR 2013 (124.8 million hectares).

[d] The area figure for Tasmania for 2013 is from *State of the forests Tasmania 2012* (FPA 2012b), and does not include the area of private land excluded from harvesting.

Source: ABARES; Australian Government Department of the Environment and Energy (CAPAD) for IUCN data; state and territory agencies.

This table, together with other data for Indicator 4.1a, is available in Microsoft Excel via www.doi.org/10.25814/5bda9272d76d7

Management Framework 2016, established under the *Victorian Water Act 1989*, includes a range of mechanisms to protect water supplies, including the declaration of water supply protection areas.

In the Northern Territory, the *Codes of Practice for Forestry Plantations* (DRPI 2004) consists of 26 goal statements that collectively cover the main requirements for sound plantation planning and management. The Northern Territory also has *Land Clearing Guidelines*[168] developed by the then Department of Natural Resources, Environment, the Arts and Sport[169]. The management of impacts on water resources and soil in the Northern Territory is also regulated under the *Water Act 2011*, *Waste Management and Pollution Control Act 2000* and *Soil Conservation and Land Utilisation Act 1985*.

In Tasmania, soil and water values are protected on forest land, particularly through the Forest Practices Code 2015 (FPA 2015b) and the *Tasmanian Reserve Management Code of Practice 2003* (Parks and Wildlife Service et al. 2003). The *Forest Practices Code 2015* (previously *Forest Practices Code 2000*) prescribes specific management measures for forest practices on any forest lands, particularly for activities associated with roads, harvesting or reforestation; a set of amendments to the code in 2015 provided standards for forest management, timber harvesting and other forest operations. The *Tasmanian Reserve Management Code of Practice 2003* aims to maintain or restore the natural quality of water and to maintain or restore natural soil processes and avoid soil degradation, within reserved lands.

In Queensland, the *Forestry Act 1959* requires state forests to be used and managed in a manner to protect water quality; the *Environmental Protection Act 1994* and the *Water Act 2000* are the main legislative instruments under which water is protected while supporting ecologically sustainable development. Risks to water quality from wood production are managed largely through codes of practice. In 2013, the Queensland Government introduced a range of self-assessable vegetation clearing codes (now called 'accepted development vegetation clearing codes'[170]) in accordance with the *Vegetation Management Act 1999*. For freehold land, the *Managing a native forest practice – A self-assessable vegetation clearing code (2014)* requires harvesting or removal of vegetation to be carried out in a way that maintains water quality values, through buffers and filter zones.

Area of public forest managed specifically to supply water for human or industrial use

A total of 1.27 million hectares of forested land is recorded as being managed exclusively to supply water for human or industrial use (Table 4.2). This area is a subset of areas of forest managed primarily for protection of soil and water values (Table 4.1). The exception is Western Australia where, in the south-west forest region, some wood harvesting is permitted in multiple-use public forest in catchments managed for water supply.

The Cotter catchment is almost wholly located within the Australian Capital Territory, and feeds into the Corin, Bendora and Cotter dams. Much of the 48 thousand hectares of the catchment area, which includes 44 thousand hectares in Namadgi National Park in the ACT as well as an adjacent area within NSW, is forested. The entire catchment is closed, with no farms or houses, and with restrictions on activities within the catchment in order to protect the quality of the water[171]. The figure of 48 thousand hectares of forest for the ACT in 2011 reported in SOFR 2013 is an error, as that figure includes that small area of the catchment that is in New South Wales.

In New South Wales, approximately 318 thousand hectares of forest are managed specifically for water supply in closed catchments from which human disturbance activities are excluded. These catchments are described further in Case study 7.1 *NSW Special Areas Strategic Plan of Management 2015*. The increase in the forest area reported for New South Wales has occurred because some land tenure categories were not included in the 2011 data reported in SOFR 2013.

In the Northern Territory, the Manton Dam and Darwin River Dam catchments are closed water catchments set aside solely for the protection of domestic water supply. The combined area of these catchments is 29 thousand hectares, much of which is forest.

Collectively, Victoria's declared water supply catchments cover 1.2 million hectares of nature conservation reserves, 1.8 million hectares of multiple-use forests, and 2.3 million hectares of other land, totalling 5.3 million hectares; on average, 68% of land within those catchments is forested (DEPI 2014d). This total includes 157 thousand hectares of closed catchments, which comprise approximately 77 thousand hectares of nature conservation reserves, 71 thousand hectares of multiple-use forests and 9 thousand hectares of private land.

Current data are not available for the area of forests in catchments explicitly managed for water production in Tasmania. Many catchments in the Comprehensive, Adequate, Representative (CAR) reserve system are used for water production, although the majority are not specifically reserved as water catchment areas. The 5 thousand hectares reported comprises forested catchments within Wellington Park and Mount Field National Park that are managed to supply drinking water to Hobart (FPA 2017a).

[168] nt.gov.au/__data/assets/pdf_file/0007/236815/land-clearing-guidelines.pdf

[169] From October 2012, the Department of Land Resource Management, and from September 2016, the Department of Environment and Natural Resources.

[170] www.qld.gov.au/environment/land/vegetation/codes

[171] www.iconwater.com.au/water-and-sewerage-system/water-and-sewerage-system/catchments.aspx

Table 4.2: Area of forest in catchments managed specifically to supply water for human or industrial use

	ACT	NSW	NT[a]	Qld	SA[b]	Tas.[c]	Vic.	WA	Australia	
	Area ('000 hectares)								Area ('000 hectares)	Proportion of total forest
2016	44	318[d]	29	n.a.	1	5	157	714	1,268	0.9%
2011	48	178[e]	29	n.a.	1	5	157	948[f]	1,366	1.1%

n.a., not available

[a] Includes forested and non-forested areas of catchments.

[b] Area of multiple-use public forest managed by ForestrySA (pine forests on land managed by SA Water); does not include native vegetation and grassland areas in reservoir protection areas. Area unchanged from that reported in SOFR 2008 as no significant change in the area, although some forest has been harvested and replanted.

[c] Tasmanian area figure from SOFR 2008.

[d] Forest in WaterNSW Protected & Special Areas on leasehold, multiple-use public forest and nature conservation reserves.

[e] Area of closed catchments on multiple-use public forest only.

[f] Includes only the public drinking water source areas on multiple-use public forest and conservation reserves in south-west of Western Australia.

This table, together with other data for Indicator 4.1a, is available in Microsoft Excel via www.doi.org/10.25814/5bda9272d76d7

In Western Australia, public drinking-water source areas include both underground water pollution-control areas and catchment areas, including water reserves. Catchments identified as sensitive to rises in saline groundwater are managed to minimise this risk; management has included re-establishing deep-rooted perennial vegetation over significant parts of the landscape. Several water reserves have been revoked since 2011 because they are no longer required for drinking water supply. The commercial pine plantation on the Gnangara Mound, north of Perth, is being reduced in size, and being replaced over time with other land covers or uses designed to increase the recharge of that water resource.

Revegetation for erosion control, New South Wales.

Rehabilitation and reforestation for protective functions

Many conservation organisations and community groups across Australia plant trees to protect riparian zones, manage ground water-tables and salinity, provide wildlife corridors and arrest soil erosion. These plantings include a large range of projects supported by the Australian and state and territory governments and the private sector. For example, through the '20 Million Trees Programme'[172], Landcare Australia has implemented revegetation projects aiming to establish tree-based ecosystems. To date these cover 3,500 hectares. While these projects are aimed primarily at restoration of wildlife habitat, they also provide soil conservation and water quality benefits.

[172] landcareaustralia.org.au/our-programme/20-million-trees/

Indicator 4.1b

Management of the risk of soil erosion in forests

Rationale

This indicator assesses the extent to which the risk of soil erosion has been explicitly identified and addressed in forest management. The avoidance of soil erosion reflects the extent to which associated values, including soil fertility and water quality, are protected.

Key points

- All Australian states and territories have a combination of legally binding and non-legally binding instruments, such as legislation, regulations, licences, codes of forest practice, guidelines and management plans, which provide for the avoidance, prevention or mitigation of soil erosion that might result from activities on forested land. All jurisdictions also have processes to ensure compliance with measures to mitigate or prevent soil erosion.
- In some jurisdictions, the forest practices system contains comprehensive soil assessment measures for determining soil properties and managing soil erosion risk in multiple-use public forests.
- This indicator reports mainly on multiple-use public forest and nature conservation reserves because, in most jurisdictions, limited information is available for forested land under other tenures.

Soil erosion is the relocation of soil by environmental forces – that is, the loss of soil from one area and its deposition into another. Minimisation of soil erosion through avoidance, prevention or mitigation[173] is essential to protecting soil and water values in forested areas, and is critical to maintaining many other forest values. Soil conservation measures are therefore an essential part of sustainable forest management.

Soil erosion on forested lands can be minimised through careful planning and implementation of forest management activities. Management actions taken to minimise soil erosion can vary greatly, depending on the nature of the forest soil and the activities being undertaken. Key forest management considerations include the use of appropriate machinery, avoiding disturbance in high-risk areas, timing of activities, and retaining vegetation. Activities for which soil management needs to be considered include road and track construction and maintenance, operations in or near streams or riparian areas, construction of stream crossings, construction of extraction tracks or other temporary tracks, placement and management of log landings, wet-weather operations, and use of heavy machinery and operations on slopes.

This indicator reports on measures required with regard to soil erosion on forested land, and external auditing of compliance with implementation of these measures. The indicator reports mainly on multiple-use public forest and (to some extent) nature conservation reserves because, in most jurisdictions, limited information is available for forested land under other tenures. Performance ratings reported are the results of assessment by the jurisdictions, and review of documents published during the reporting period.

Legally binding and non-legally binding instruments in Australian state and territory jurisdictions provide guidance and measures to address soil erosion associated with forestry operations. Codes of forest practice, for example, generally require wood harvesting to occur in ways that prevent and/or mitigate soil erosion, particularly for locations that are most susceptible. Soil erosion can also result from bushfire and recreational activities, particularly around roads, walking trails, picnic areas and campsites. The risk of soil erosion caused by recreational activities is generally managed through appropriate design, construction, access to and use of relevant infrastructure, with access potentially limited during periods of rehabilitation after bushfire.

[173] The term 'minimise' is used in this indicator to cover each of the different steps of avoiding, preventing and mitigating erosion. In this context, 'avoidance' is the selection of management actions that do not lead to erosion, 'prevention' is incorporation of provisions into actions so that erosion does not occur, and 'mitigation' is reducing the negative impacts of any erosion that results from management actions.

Instruments that address the risk of soil erosion

Measures that can be undertaken during forest operations to minimise soil erosion include:

- excluding identified vulnerable areas, including karst terrain, wetlands, and areas with high erosion hazard or landslip potential
- providing road drainage, such as well-designed culverts and table drains, and providing drainage to log extraction tracks such as cross-drains and drainage channels
- appropriate arrangement of log extraction tracks, for example by contouring, walk-over extraction, and appropriate location of log dumps and landings (such as on naturally flat land on ridges and saddles)
- minimising stream crossings, or using well-designed bridges, fords or natural causeways
- protecting riparian zones using buffers or filters
- ceasing operations or closing forests for defined periods of wet weather
- rehabilitating log landings and extraction tracks by, for example, ripping, replacement of topsoil, and/or planting.

In all jurisdictions, measures to minimise soil erosion were in place for the reporting period, but some do not cover all forest tenures. In Victoria and Tasmania, however, such measures apply to all forest harvesting operations regardless of tenure.

In the ACT, the legally binding instruments that address conservation and maintenance of soil resources are the *Public Unleased Land Act 2013*, the *Environment Protection Act 1997* and the *Nature Conservation Act 2014*. However, these instruments do not specify that the components listed in Table 4.3, Category 1, are to be taken into account in addressing the risk of soil erosion from forest disturbances. The ACT *Code of Forest Practice 2005*[174] is a non-legally binding instrument that recognises the importance of protecting soil from erosion and other degradation, and covers all components listed in Category 1 except for wind erosion. The code was reviewed by Smethurst et al. (2012) and its processes were deemed adequate for soil protection during plantation forestry activities in the ACT.

In Victoria, the *Sustainable Forests (Timber Harvesting) Regulations 2006* were revoked in 2014, and the *Code of Practice for Timber Production 2014*[175] is the key regulatory instrument that applies to timber production in public and private native forests and plantations in Victoria. It is a statutory document under the *Conservation, Forests and Lands Act 1987*. The code addresses the risk of soil erosion from disturbance activities such as rainfall, slope, soil erodibility, and management practices such as regeneration or establishment, timber harvesting and roading. Soil erosion is minimised by avoiding harvesting in inappropriate areas or slopes and undertaking necessary preventive measures. During or following wet weather conditions, timber harvesting operations are modified or where necessary suspended to minimise risks to soil values. Site preparation operations take into account the maintenance of soil values.

Environmental care principles of the Victorian *Code of Practice for Bushfire Management on Public Land 2012*[176] (DSE 2012) include a requirement that the soil be protected during fire management activities, either by preventing inappropriate destruction of its physical and chemical properties or by promoting stabilisation of bare or disturbed earth following disturbance. Under this code, the then Department of Sustainability and Environment (DSE[177]) must prepare maps that show areas that are particularly sensitive to soil disturbances, and these maps must be considered when planning the use of heavy machinery during firefighting operations. The code also includes a requirement to assess risk to natural values, including soil, in both the emergency stabilisation and recovery phases of bushfire response (DEPI 2014d).

New South Wales has legally binding instruments that address the risk of soil erosion in both the native forest and plantation estates. In the New South Wales multiple-use public forest estate, Integrated Forestry Operations Approvals (IFOAs) contain requirements for assessing and managing risks to soil erosion and risks of water pollution. The IFOAs contain the terms of a licence under the *Protection of the Environment Operations Act 1997* (NSW) (the 'environment protection licence'). The purposes of the environment protection licence include to control the carrying out of forestry operations, including harvesting, thinning and road construction, in a way that avoids, prevents or mitigates soil erosion. The *Private Native Forestry Code of Practice 2013*[178] aims to achieve these purposes for the private native forest estate in New South Wales.

Softwood and hardwood plantations in New South Wales are authorised under the *Plantation and Reafforestation (Code) Regulation 2001*, which prescribes standards and regulations relating to the protection of soil and water. Prescriptions cover buffer zones, slope limits, wet weather provisions, and road, crossing and drainage location, design and requirements for construction, maintenance and management during operations.

In New South Wales conservation reserves, the *National Parks and Wildlife Act 1974*, *National Parks and Wildlife Regulation 2009* and other codes, procedures and guidelines address the risk of soil erosion, including when environmental impact assessment is required prior to approval of and consent for works.

[174] www.environment.act.gov.au/__data/assets/pdf_file/0003/1126353/ACT-Code-of-Forest-Practices-2005.pdf

[175] www.forestsandreserves.vic.gov.au/__data/assets/pdf_file/0016/29311/Code-of-Practice-for-Timber-Production-2014.pdf

[176] www.ffm.vic.gov.au/__data/assets/pdf_file/0006/21300/Code-of-Practice-for-Bushfire-Management-on-Public-Land.pdf

[177] From January 2015, the Department of Environment, Land, Water and Planning.

[178] www.epa.nsw.gov.au/your-environment/native-forestry/about-private-native-forestry/private-native-forestry-code-practice ; see also www.lls.nsw.gov.au/sustainable-land-management/pnforestry

In the Northern Territory, the *Soil Conservation and Land Utilisation Act 1985* is the main legislation that provides powers to the Northern Territory Government for monitoring and controlling risks to soil resources. Under this Act, areas of land that are subject to soil erosion or areas at risk of potential soil erosion may be declared Areas of Erosion Hazard, and an area of land that is subject to soil erosion through use by the public may be declared a Restricted Use Area. Although the Act does not have specific reference to forestry, Soil Conservation Orders can be made by the Soil Commissioner to prescribe infrastructure planning, land use, and remediation practices to protect soil resources during any crop land preparation including plantation forests (Raison et al. 2012). The Northern Territory *Codes of Practice for Forestry Plantations* (DRPI 2004) contains goals that relate to the protection of soil values. The code was reviewed in 2012, with recommendations including addition of specific guidance for the protection of soil values during establishment, management and harvesting of plantations (Raison et al. 2012). *Land Clearing Guidelines* (Northern Territory Government 2010) provide some broad advice on how to minimise soil disturbance during the removal of native vegetation. In addition, management plans for conservation reserves include provisions to minimise soil erosion.

In Western Australia, the *Forest Management Plan 2004–2013* (CCWA 2004) and the *Forest Management Plan 2014–2023* (CCWA 2013) operate under the *Conservation and Land Management Act 1984*. Both plans focus on the management of state forest and timber reserves and plantations, and have aims that include protecting soil and water values. They prescribe measures to minimise unnecessary adverse soil disturbance, protect soil from erosion and prevent damage, as well as remedial measures to restore soil when damage occurs. All management activities prescribed in the plan are required to be conducted in accordance with associated manuals and guidelines such as *Soil and Water Conservation Guideline 2009* (DPaW 2009a), *Manual of Procedures for the Management of Soils Associated with Timber Harvesting in Native Forests 2010* (DPaW 2010) and *Manual for the Management of Surface Water 2009* (DPaW 2009b).

Western Australia's *Soil and Water Conservation Guideline 2009* sets out the key requirements for protecting soil, based on the types of disturbance, and limits activities for various levels of disturbance. Ten guiding principles are described to protect soils, including rehabilitation of damaged soil, and protection of soil from erosion as a result of wood harvesting and associated forest management activities. The *Manual of Procedures for the Management of Soils Associated with Timber Harvesting in Native Forests 2010* (DPaW 2010) provides guidance to reduce the extent and severity of soil disturbance associated with timber harvesting in native forests. It includes a trafficability index that defines soil management risk periods and permissible activities in relation to soil moisture, and introduces a precautionary planning approach to halt operations prior to exceeding allowable limits. During the reporting period, this manual was updated twice to support continual improvement in practices for the management of soil values during timber harvesting activities. The *Code of Practice for Fire Management 2008*[179] prescribes measures to manage fires while protecting soil stability and soil rehabilitation following disturbance to minimise the threat of soil erosion. *The Code of Practice for Timber Plantations in Western Australia* (FIFWA 2014) provides guidelines for soil protection in plantations in Western Australia.

In Tasmania, forestry activities are regulated by the Forest Practices Authority (FPA) in accordance with the *Forest Practices Act 1985*. The *Forest Practices Act 1985* requires assessment of risks to soils when a forest activity is carried out, irrespective of land tenure or forest type. Assessments are also commonly undertaken on public forests and large, industrially managed private forests in relation to road and site developments and ongoing maintenance, although these are not specified under the *Forest Practices Act 1985*. The *Forest Practices Code 2015*[180] (FPA 2015b) is legally enforceable under the Act for both public and private forest. The code requires forest practices to be conducted in a manner that maintains soil fertility and does not cause significant deviations from natural rates of erosion and landslides. Forest practices plans need to be prepared under Section 18 of the Act in accordance with the code, and contain instructions for protecting soil values during forestry operations such as timber harvesting and road construction.

In Queensland, State Forests are used and managed in a manner to conserve soil under the *Forestry Act 1959*. In 2013, the Queensland Government introduced self-assessable vegetation clearing codes (SACs) in accordance with the *Vegetation Management Act 1999*. The code *Managing a native forest practice*[181] (DNRM 2014) applies to native forest practices on freehold and Indigenous land, and regulates activities such as planting, silvicultural thinning and selective, very low intensity or small-scale harvesting. Snigging is not allowed in a filter zone, and roads and tracks are to be properly designed, located or managed to prevent accelerated soil erosion. Harvesting is restricted in wet weather when the soil is saturated. Fuel-reduction burning is timed to avoid periods of high-intensity rainfall, and is conducted at low fire intensity to leave unburnt litter and prevent accelerated soil erosion.

Plantation activities in Queensland are governed by several Acts, and associated subordinate legislation, policies and codes depending on the land tenure. Under the *Soil Conservation Act 1986*, plantation operators in Queensland are required to conserve soil resources and facilitate the implementation of soil conservation measures to mitigate soil erosion. *Timber Plantation Operations Code of Practice for Queensland 2015*[182] (Timber Queensland 2015) is a non-legally binding instrument. It requires a plantation management plan to be prepared prior to operations. Soil erosion is minimised by avoiding timber production in inappropriate areas or slopes, and using appropriate harvesting methods (e.g. cable

[179] www.dpaw.wa.gov.au/images/documents/fire/fms-code-of-practice.pdf

[180] www.fpa.tas.gov.au/fpa_services/planning_assistance/forest_practices_code

[181] publications.qld.gov.au/dataset/self-assessable-vegetation-clearing-codes/resource/a73f5b44-008c-4f92-8644-f92e6caf6592

[182] www.timberqueensland.com.au/Docs/Growing-Processing/Timber-Plantation-Operations-Code-of-Practice-Version-1.pdf

harvesting or modified excavator based methods) where conventional harvest methods are considered unsafe or may threaten the stability of the soil or may have potential for adverse off-site effects. Soil erodibility and rainfall erosivity are considered when embankments, plantation roads and fill disposal areas are designed and managed to minimise soil erosion and mass movement.

In South Australia, under the *Forestry Regulations 2013* a person must not intentionally destroy, damage or disturb any soil in a public forest reserve without lawful authority. Plantation and other land managers have an obligation to manage and protect soil resources and prevent the degradation of land, primarily under the *Natural Resources Management Act 2004*. The *Guidelines for Plantation Forestry in South Australia 2009*[183] emphasize the importance of minimising soil disturbance, soil compaction and impact on run-off during plantation establishment, maintenance, harvesting and road construction. This is done through references to mandatory requirements and industry best-practice. Revised guidelines are due to come into operation in 2018.

Assessment of legal instruments and regulatory framework

The extent to which a regulatory framework requires the maintenance of soil values is rated according to the five categories used in previous SOFRs (Table 4.3), ranging from Category 1 (for regulatory instruments that are applicable to all erosion processes and that take into account many types of erosion risk) to Category 5 (for instruments that do not mention the need to address risks of soil erosion). The extent to which the risk of soil erosion is addressed by a state or territory's legally binding instruments (such as Acts) and non-legally binding instruments (such as codes of practice, guidelines and forest management plans) is assessed against these criteria in Table 4.4. The regulatory frameworks in a number of jurisdictions are now rated in a higher category than they were in SOFR 2013.

Table 4.3: Categories of the extent to which the regulatory framework requires the maintenance of soil values

Category	Category description
1	The instruments require rainfall intensity, slope, soil erodibility and management practices that result in soil disturbance to be taken into account in addressing the risk of soil erosion from disturbance activities, and the instruments are applicable to all erosion processes, including erosion due to wind, sheet, rill, gully, tunnel, stream bank, wave and mass movement.
2	The instruments address most of the components listed in category 1, and those not addressed are associated with low risks of soil erosion for the particular disturbance activity and geographical setting.
3	The instruments address most of the components listed in category 1 but do not specify all aspects or are limited in their application.
4	The instruments mention the need to address risks of soil erosion when conducting disturbance activities but do not specify the components listed in category 1.
5	The instruments do not mention the need to address risks of soil erosion.

Source: SOFR 2008.

Table 4.4: Assessed extent to which legally and non-legally binding instruments address the risk of soil erosion due to forest operations, road and trail works, and recreation activities

Instrument	Tenure	ACT	NSW	NT	Qld	SA	Tas.	Vic.	WA
Legally binding	Multiple-use public forests and plantations	4	1	1–4	2	4	1	1	4
	Public nature conservation reserves	4	1–2	1	n.a	4	1–2	1	4
	Leasehold land	4	1–2	1–4	2	4	n.r.	n.r.	n.r.
Non-legally binding	Multiple-use public forests and plantations	2	1	3	2	1–4	1	3	1[a]
	Public nature conservation reserves	2	1–3	3	n.a	n.a.	1–2	3	4
	Leasehold land	2	n.r.	3	n.a	1–4	n.r.	n.r.	n.r.

n.a., not applicable; n.r., not reported

[a] Based on ABARES assessment of the *Manual of Procedures for the Management of Soils Associated with Timber Harvesting in Native Forests 2010* (DPaW 2010).

Note: Categories for assessing the risk of soil erosion range from 1 (highest rating) to 5 (lowest rating): see Table 4.3. Each rating is an assessment by the relevant jurisdiction for the period 2011–16, except that data for Victoria are from SOFR 2013 and data for Tasmania are from FPA (2017a).

Source: State and territory agencies, and ABARES.

This table, together with other data for Indicator 4.1b, is available in Microsoft Excel via www.doi.org/10.25814/5bda9272d76d7

[183] www.pir.sa.gov.au/__data/assets/pdf_file/0011/254765/guidelines_for_plantation_forestry_in_sa_web.pdf

Legally binding instruments regulating native forest harvesting are in place in New South Wales, Victoria, Tasmania, Western Australia and Queensland. Native forest harvesting is not allowed in the Australian Capital Territory or South Australia, and only limited harvesting occurs on private land in the Northern Territory. Overall, there has been no major change during the reporting period in the way legally and non-legally binding instruments address the risks to maintenance of soil values.

Assessment of erosion hazard

Erosion hazard is generally assessed using overlays of available information in geographic information systems. Relevant information includes erosion hazard maps, geographical settings such as slope, soil erodibility, rainfall intensity, and management practices that could contribute to soil erosion. This provides forest managers with information on the level and location of erosion hazards, which is then used to determine appropriate measures to minimise erosion risk. Examples of research designed to increase the knowledge base on soil erosion are given in Case Study 4.1.

The extent to which risks of soil erosion are assessed in planning processes is rated according to the four categories used in previous SOFRs. These categories are detailed in Table 4.5, and range from Category 1 (for a risk assessment system that takes account of erosion risks associated with rainfall intensity, slope, soil erodibility, and management practices that could contribute to soil disturbance) to Category 4 (for a risk assessment system that is ad hoc or does not take into account any erosion processes).

The area of multiple-use public forest for which disturbance activities were planned, the proportion of that area that was assessed for risk of soil erosion, and the extent to which risks of soil erosion are assessed in planning processes, are shown in Table 4.6, using the categories from Table 4.5.

Table 4.5: Categories of the extent to which the risks of soil erosion are assessed in planning processes

Category	Category description
1	The soil erosion risk assessment system comprehensively takes account of rainfall intensity, slope, soil erodibility and management practices that could contribute to soil disturbance.
2	The soil erosion risk assessment system takes into account most of the components listed in category 1, and those not addressed are associated with low risks to soil values for the particular disturbance activity and geographical setting.
3	The soil erosion risk assessment system takes into account some of the factors listed in category 1 or only partly accounts for these factors.
4	The soil erosion risk assessment system is ad hoc and/or does not take into account any of the factors listed in category 1.

Source: SOFR 2008.

Table 4.6: Area of multiple-use public forest where disturbance activities were planned, proportion assessed for risk of soil erosion, and assessed category

Disturbance activity	Metric	ACT	NSW	NT	Qld	SA	Tas.	Vic.	WA
Native forest harvesting and silviculture	Area (hectares)	0	17,000–32,000	n.a.	n.r.	0	n.r.	n.r.	n.r.
	Proportion assessed for risk of soil erosion (%)	n.a.	100	n.a.	100	n.a.	n.r.	n.r.	n.r.
	Assessed category[a]	n.a.	1	n.a.	2	n.a.	1	2	3
Plantation operations	Area (hectares)	627	7,000–10,000	n.a.	n.r.	n.r.	n.r.	n.r.	n.r.
	Proportion assessed for risk of soil erosion (%)	100	100	n.a.	n.r.	100	n.r.	n.r.	n.a.
	Assessed category[a]	1	1	n.a.	n.a.	1	1	n.a.	n.a.
Road construction and maintenance	Area (hectares)	n.r.	n.r.	n.a.	n.r.	n.r.	n.r.	n.r.	n.r.
	Proportion assessed for risk of soil erosion (%)	n.r.	n.r.	n.a.	n.r.	100	n.r.	n.r.	n.r.
	Assessed category[a]	n.a.	n.a.	n.a.	2	3	1	n.a.	3
Fire management	Area (hectares)	n.r.	20,000–40,000	n.a.	n.r.	n.r.	n.r.	n.r.	n.r.
	Proportion assessed for risk of soil erosion (%)	n.r.	n.r.	n.a.	n.r.	100	n.r.	90	n.a.
	Assessed category[a]	n.a.	3	n.a.	n.a.	3	1	2	n.a.

n.a. = not applicable; n.r. = not reported for this indicator

[a] The extent to which risks of soil erosion are assessed in planning processes varies between 1 (highest rating) and 5 (lowest rating): see Table 4.5 for details.

Note: NT has no multiple-use public forests. Areas harvested are reported in Indicator 2.1a.

Source: The data shown are from SOFR 2013 except for data for ACT and NSW, which were provided by the ACT Environment and Sustainable Development Directorate and Forestry Corporation of NSW, respectively. NSW figures are the range of annual areas across the five-year reporting period.

This table, together with other data for Indicator 4.1b, is available in Microsoft Excel via www.doi.org/10.25814/5bda9272d76d7

Data is available for Table 4.6 only for few activities and jurisdictions. However, there are regulatory instruments in all jurisdictions that require that the risks of soil erosion associated with the listed disturbance activities in multiple-use public forests be assessed, and that preventative and remediation practices are implemented.

In the ACT, a comprehensive soil erosion risk assessment is completed under the ACT *Code of Forest Practice 2005*[184] (Environment ACT 2005), which takes account of soil erodibility, rainfall intensity, slope and management practice. The code groups soil erodibility into five classes, provides guidance for plantation operations, and describes actions to be taken according to the soil erodibility class for a given area. All plantation areas where disturbance activities are planned during the reporting period were formally assessed for risk to soil erosion.

In South Australia, suitability of a site for plantation forestry is identified by assessing soil characteristics and classifying land capability classes. For example, soil properties are assessed and taken into account in operational planning within the Green Triangle Forest Products defined forest area in South Australia, to manage adverse changes to soil values (Green Triangle Forest Products 2015). Forest operations are planned on the basis that well-drained soils are more robust in winter, while heavier soils or soils with a water-retaining layer may be damaged by operations during the wetter months. In addition, regional natural resource management plans are prepared for multiple-use forest, nature conservation reserves and other crown lands that include a summary of threats and issues relating to soil, including erosion.

The Forestry Corporation of NSW undertakes comprehensive soil assessments as required under the Environmental Protection Licence for native forest operations and the *Plantations and Reafforestation (Code) Regulation 2001* for public and private plantations. These assess inherent soil erosion and water pollution, mass movement, dispersibility, and seasonality, with all four assessments applied during a pre-operational planning phase. Assessments are used to determine the level of protection required at each site to conserve soil values.

Under the *National Parks and Wildlife Act 1974* and *National Parks and Wildlife Regulation 2009*, the NSW National Parks and Wildlife Service is required to assess the environmental impacts of earthworks that are part of new road, track and trail construction or upgrades to the existing road, trail and track network. New trail construction requires a formal assessment under Part 5 of the *Environmental Planning and Assessment Act 1979*. Under the policy of the NSW National Parks and Wildlife Service, most maintenance also requires a conservation risk assessment. The *Bush Fire Environmental Assessment Code for New South Wales 2006* provides standards to prevent soil erosion and instability for bushfire hazard reduction works.

In Victoria, field assessments under the *Code of Practice for Timber Production 2014*[185] (DEPI 2014b) and the *Management Standards and Procedures for Timber Harvesting Operations in Victoria's State Forests 2014*[186] (DEPI 2014c) are conducted by DELWP and VicForests staff, to determine the soil erosion hazard and soil permeability classifications for an area proposed for timber harvesting operations. Forest Coupe Plans are prepared by VicForests for all areas planned for harvest, prior to operations commencing, and include a map of soil erosion hazard class and soil permeability class. Coupes are managed based on their highest erosion class, to ensure the risk of erosion is controlled.

In Tasmania, preparing a Forest Practices Plan under the *Forest Practices Code 2015*[187] (FPA 2015b) requires a detailed evaluation of soil properties. Erosion hazard assessment in Tasmanian forests includes a soil erodibility classification derived from observations of soil morphology (and soil mapping in some areas) and from laboratory soil erodibility data. The Code also takes into account the risk of landslides and the risks associated with operations in karst terrain. State forests are assessed to identify 'High Conservation Values' (HCVs), and additional management actions to protect these values are prescribed if required; the latest HCV assessment did not identify any forest where removal of trees through harvesting managed under the Forest Practices Code would have a critical effect on soil erosion. The *Guidelines for the Protection of Class 4 Streams* (FPA 2011a)[188] are used to classify Class 4 streams and adjacent riparian zones into one of five erosion hazard classes based on slope and soil erodibility, and to select the appropriate prescriptions for the type of operation being planned. Some soil types have required special consideration as they have proved to be less erodible that previously thought. For example, the Forest Practices Authority has recently developed *Prescriptions and guidelines for sustainable harvest of plantations on high and very high erodibility west coast dune sands* (FPA 2015b).

In Queensland, erosion risk is addressed in a code of practice attached as a required condition to public land timber sales permits issued under the authority of the *Forestry Act 1959*. A second edition of the *Guidelines for agricultural land evaluation in Queensland*[189] was published in 2015, and there are also regional land suitability frameworks. Under *Managing a native forest practice – A self-assessable code for managing a native forest practice (2014)*[190] (DNRM 2014), native forest operators assess the soil prior to forest operations for inherent erodibility, slope, slope length, ground cover and land erosivity to identify erosion hazards. Sites are excluded from operation where the hazard is rated high, unacceptable or unmanageable, while operational conditions (e.g. timing in relation to weather and techniques) are established to minimise the potential for damage where the hazard is rated acceptable.

184 www.environment.act.gov.au/__data/assets/pdf_file/0003/1126353/ACT-Code-of-Forest-Practices-2005.pdf

185 www.forestsandreserves.vic.gov.au/__data/assets/pdf_file/0016/29311/Code-of-Practice-for-Timber-Production-2014.pdf

186 www.forestsandreserves.vic.gov.au/__data/assets/pdf_file/0023/29309/Management-Standards-and-Procedures-for-timber-harvesting-operations-in-Vics-State-forests-2014.pdf

187 www.fpa.tas.gov.au/fpa_services/planning_assistance/forest_practices_code

188 www.fpa.tas.gov.au/__data/assets/pdf_file/0014/110246/Guidelines_for_the_protection_of_Class_4_streams.pdf

189 publications.qld.gov.au/dataset/qld-agricultural-land-evaluation-guidelines

190 pfsq.net/wp-content/2017/03/2015-managing-native-forest-practice-code.pdf

Case study 4.1: Soil erosion knowledge base

This case study gives examples of research designed to increase the knowledge base on soil erosion in New South Wales.

'Paired catchment' studies detect the effects of wood harvesting and other disturbances by comparing stream flow and soil erosion in adjacent, similar, disturbed and undisturbed catchments. In one such study, Forestry Corporation of NSW researchers have monitored eight headwater catchments of the Karuah River in the Chichester State Forest since 1974. The catchments, which range from 15 to 100 hectares, were originally predominantly undisturbed tall eucalypt forest from 100 to over 500 years since disturbance, and with little evidence of fire. Weirs were installed at the outlet to each catchment so that stream flow and sediment carried in the streams could be measured.

After an initial period of monitoring to establish a baseline of stream flow and water quality, in 1983 a total of six catchments were subjected to various levels of wood harvesting, plantation establishment, road construction and other disturbance, while two were left undisturbed as controls. This is one of few studies to report long-term erosion rates for similar undisturbed and harvested sites in eastern Australia. Erosion rates ranged from 0.47 to 1.40 tonnes of sediment per hectare per year. There was no difference in sediment loads from the harvested and control catchments. The researchers concluded that harvesting in native forests followed by regeneration using best management practices does not cause significant soil erosion, or reduce water quality in the medium-term to long-term (Hancock et al. 2017).

Jamshidi et al. (2014) assessed annual changes in sediment loads in streams in four catchments in Kangaroo River State forest (NSW). Two catchments were selectively logged in 2007, while the other two were undisturbed. After selective logging, a greater amount of eroded sediments was transported to catchment outlets from steeply sloping areas close to catchment outlets during high rainfall events, than from distant hillslope areas. Vegetation cover recovered almost to its initial pre-logging condition after two years (2009), however sediment loads increased by up to 30% when more storm events were recorded in the same year. In all catchments, sediment delivery was influenced significantly more by rainfall than by changes in land cover. The study supports the current single-tree selection logging system as an environmentally sound land management strategy that minimises soil loss and sediment movement.

Stream flow and sediment monitoring weir, Karuah catchment research, NSW.

In south-west Western Australia, during the reporting period the Department of Parks and Wildlife (DPaW) and the Forest Products Commission (FPC) have used soil landform maps in wood harvest planning and the management of soil erosion risks (DPaW 2016a). While there is no formal process in place to update soil data, field assessment continues to inform continual improvement in the understanding of soil disturbance and wood harvesting (DPaW 2016a).

Compliance with measures to mitigate impacts on soils

Compliance with requirements for minimisation of soil impacts is assessed in various ways across Australia, including by internal and external audits. The extent of compliance with prescribed mitigation measures for soil impacts is rated according to the seven categories used in previous SOFRs. These categories are detailed in Table 4.7, and range from Category 1 (for performance fully compliant with all requirements and outcomes, with minimal adverse impacts) to Category 7 (where no formal audit was conducted). Table 4.8 gives the compliance outcomes for some jurisdictions against these categories.

In Victoria, the Forest Audit Program (FAP) systematically assesses risks to soil attributes due to timber production operations through audits of compliance (DEPI 2014d). The Department of Environment, Land, Water and Planning (DELWP) has been responsible for the FAP since 2011, and commissions audits to measure industry compliance with the requirements set out in the *Code of Practice for Timber Production 2014*. According to the latest independent audit report, audited coupes were in compliance, with the majority of criteria achieving a compliance rate of 90% (URS Australia 2015). Coupes managed by VicForests and Department of Environment and Primary Industries (DEPI)[191] Forestry Services had an overall compliance score of 86% and 65% respectively for the 'water and soils' group of audit criteria (URS Australia 2015). Good practice was noted in the conservative classification of drainage lines; in prohibiting excavation of erosive subsoils; and in protection of soil close to active erosion points in coupes managed by DEPI Forestry

Table 4.7: Categories for the performance of forest managers in complying with prescribed mitigation measures for soil impacts

Category	Category description
1	Fully compliant with all process requirements and environmental outcome requirements, with minimal adverse impacts
2	Generally compliant with all process requirements and environmental outcome requirements, with minimal adverse impacts
3	Fully or generally compliant with all process requirements and environmental outcome requirements, but with moderate adverse impacts
4	Not generally compliant with process requirements and environmental outcome requirements, with minimal adverse impacts
5	Not generally compliant with process requirements and environmental outcome requirements, with significant adverse impacts
6	Insufficient or no objective evidence to make a judgment
7	No formal audit conducted

Source: SOFR 2008.

Table 4.8: Assessed compliance outcomes for soil impacts achieved in multiple-use public forests

Disturbance activity	ACT	NT	NSW	Qld	Vic.	SA	Tas.	WA
Native forest harvesting	n.a.	n.a.	2 (99%) 3 (1%)	1	3	n.a.	1	3
Plantation operations	1 (90%) 3 (10%)	n.a.	2 (90%) 5 (10%)	n.r.	2	3	1	4
Roads and trails	n.r.	n.a.	1–5	n.r.	2	3	1	4
Fire management	n.r.	n.a.	2, 6[a]	n.r.	2	3	1	4

n.a., not applicable; n.r., not reported

[a] '2' for conservation reserves; '6' for multiple-use state forests.

Notes: Data are for 2011–16, except that data for Vic. and Tas. are from SOFR 2013, and data for WA are from SOFR 2008. Categories for assessing compliance outcomes are described in Table 4.7, and vary between 1 (highest rating) and 7 (lowest rating). Each rating is an assessment by the relevant jurisdiction. There is no multiple-use public forest in the Northern Territory.

Source: State agencies.

This table, together with other data for Indicator 4.1b, is available in Microsoft Excel via www.doi.org/10.25814/5bda9272d76d7

[191] Data from six coupes managed by DEPI Forestry Services in the Bendigo FMA are included in the data in URS Australia (2015): see also agriculture.vic.gov.au/agriculture/forestry/wood-utilisation-plans/bendigo-forest-management-area

Ripping and mounding parallel to the contour to minimise soil erosion at plantation establishment on farmland, Adelaide Hills, South Australia.

Services. Non-compliances related to lack of risk assessment on mass soil movement on steep slopes were identified in coupes managed by VicForests. DELWP also introduced a 'rainforest spot checks' program in 2015 to examine the performance of VicForests in the identification and protection of rainforest values.

The Western Australian Department of Parks and Wildlife[192] oversees the approvals, monitoring and compliance system for disturbance activities in state forests and timber reserves. The Department audits a range of forest management activities for compliance with requirements of the *Forest Management Plan 2014–2023* (CCWA 2013) under which the Forest Products Commission of Western Australia conducts forest operations. To minimise the risk of soil erosion, spreader banks are constructed across all extraction tracks and disturbed firebreaks upon completion of log extraction. The five jarrah coupes assessed all complied with erosion control measures (DPaW 2016c). The report on the end-of-term audit of the *Forest Management Plan 2004–2013* (CCWA 2013) noted that severe and highly visual forms of soil damage, such as rutting, puddling and mixing, were rarely seen in association with wood harvesting operations.

The Forestry Corporation of NSW (FCNSW) has a comprehensive soil assessment program for forestry operations, consisting of four modules (inherent soil erosion and water pollution assessment, mass movement assessment, dispersibility assessment, and seasonality), and is required to apply all four modules during pre-operational planning. Across 1,291 compliance checks, a total of 21 non-compliances were detected, and in one instance in 2015 FCNSW was fined by the Environment Protection Authority due to a failure to implement effective erosion and sediment control measures at a clearfell harvesting operation on a native hardwood plantation, when soil from a newly harvested plantation area washed into a waterway following a heavy rainfall event before replanting. Site-specific special protection measures, such as increasing the buffer widths around streams and sowing a cover crop immediately after harvesting, are now adopted in areas at high risk of soil erosion (FCNSW 2016d).

Native forest harvesting is not permitted in the Australian Capital Territory. Ninety percent of plantation operations in the Australian Capital Territory were fully compliant with all process requirements and environmental outcome requirements, with minimal adverse impacts; the other 10% were fully or generally compliant with all process requirements and environmental outcome requirements, but with moderate adverse impacts (Table 4.8).

In Queensland, monitoring and compliance systems are in place for native forest harvesting under the *Forestry Act 1959*. The Department of Agriculture, Fisheries and Forestry[193], and the Queensland Parks and Wildlife Service, as the custodians of State forests and timber reserves in Queensland,

[192] From July 2017, the Department of Biodiversity, Conservation and Attractions.

[193] From February 2015, the Department of Agriculture and Fisheries.

audit native forest harvesting on State forests and timber reserves. Over the SOFR 2018 reporting period, there were no significant non-compliances or breaches reported for native forest activities authorised under the *Forestry Act 1959*.

In the Northern Territory, no significant non-compliance incidents or breaches under the *Soil Conservation and Land Utilization Act 2016* in regard to soil erosion on forest land were reported during the reporting period, and no infringement notices sent.

For South Australia, the *Forestry Regulations 2013* prohibit damaging soil and polluting streams. Data on breaches and non-compliance are not readily available, but are recorded in auditing processes for businesses that have forest certification. For example, as well as being bound by the *Forestry Regulations 2013*, softwood plantation manager OneFortyOne Plantations is voluntarily certified to the Australian Standard for Sustainable Forest Management (AS 4708). The most recent (June 2017) independent audit to ascertain compliance with the standard inspected a sample of 12 operational sites and found no instances of non-conformity.

In Tasmania, the Forest Practices Authority assesses forest practices that have been carried out under forest practices plans (FPP) certified under the *Forest Practices Act 1985*. Consistently high levels of compliance have been found for soil and water protection requirements issues on all tenures, demonstrating that operations are generally carried out to a very high standard and that only locally and sporadically do issues require attention (FPA 2017a).

Fire

Bushfire affects soils directly, for example through the loss of carbon and nutrients, and indirectly through rendering the soil more susceptible to erosion due to the reduction in vegetation cover. The likelihood of post-fire erosion depends on fire severity, rainfall intensity, aridity and hillslope morphology (Bell et al. 2014; Morris et al. 2012; Tulau 2015).

Catchments with vegetation communities that recover rapidly (such as by resprouting) have a substantially different post-bushfire response, with only minor erosional events, compared to vegetation communities that recover more slowly (such as if dominated by plants that regenerate only from seed) that can display serious post-bushfire erosion (Heath et al. 2014, 2016).

High-intensity rains 10 weeks after a bushfire in the Royal National Park, New South Wales, caused significant erosion from hillslopes, fire trails and walking tracks in a sandstone catchment (Atkinson 2012). Peak soil losses of 64 tonnes per hectare were recorded, compared to 2.5–8.0 tonnes per hectare from similar terrain in a relatively dry year. Similar high-rainfall events 3.5 years after the fire produced peak soil losses of 2.2 tonnes per hectare, and five years after the fire the soil loss rate had fallen to an average of 0.6 tonnes per hectare, approximately 1% of the peak soil loss rate.

Recovery from bushfires in the Warrumbungle National Park, New South Wales, in 2013 is the focus of a major program by NSW National Parks and Wildlife Service. An intense storm immediately following the bushfires caused flash-flooding and soil erosion, with an average soil loss of 150 tonnes per hectare (McInnes-Clarke et al. 2014).

Reducing bushfire severity reduces the potential for erosion issues. However, low-intensity fires such as prescribed burns can also increase the risk of erosion, particularly on erodible soils, where terrain is steep, or when there are subsequent, intense rain events. Morris et al. (2014) assessed erosion following prescribed burning in managed reserves in the Southern Mount Lofty Ranges in South Australia. Sediment movement was detected at half the prescribed burn sites, but its extent was minimal.

Indicator 4.1c

Management of the risk to soil physical properties in forests

Rationale

This indicator measures the extent to which the risk to soil physical properties in forests has been explicitly identified and addressed. The protection of soil physical properties, including minimising soil compaction and redistribution, affects soil integrity and, as a consequence, many associated values.

Key points

- In all states and territories, soil physical properties in forests are protected by a combination of legally binding and non-legally binding instruments, including legislation, regulations, licences, codes of practice, guidelines and management plans.
- In most jurisdictions, disturbance activities associated with forest management, such as wood harvesting and associated road and track construction and maintenance, were assessed for risk to soil physical properties, and protective measures were implemented.
- In most jurisdictions, the level of compliance with soil protection measures in multiple-use public forest has been assessed as high.

Appropriate management of soils as the substrate for forests is fundamental to sustainable forest management. Soil physical properties include soil structure, density, compaction, texture, permeability and water-holding capacity. Degradation of these properties can affect seed germination and growth and survival of trees, and can have other effects, such as increased water run-off and consequent erosion. It is therefore important that forest management operations do not result in permanent adverse changes to soil physical properties.

This indicator reports on the measures undertaken to minimise adverse impacts on soil physical properties on forested land. It focuses on multiple-use public forest and public nature conservation reserves because, generally, limited information is available for other forest tenures.

Impacts of forestry operations on soils

The principal impacts of forestry operations on the physical properties of soils are associated with wood production and include tree-felling and snigging or forwarding, activities at log dumps and log landings, preparing sites for regeneration or planting, and construction of roads, trails and log extraction tracks (snig tracks). Common potential impacts of these forest disturbance activities are soil compaction, soil movement, and removal of organic matter. The impact of heavy-tracked vehicles, in particular, on the physical characteristics of soils is immediate and generally obvious, but the degree of impact depends on the soil type, the soil moisture content, the loading pressure, and the duration and frequency of such pressure, including the number of times a vehicle passes over a track.

The physical impact on soils from wood harvesting can be minimised by using appropriate harvesting equipment, harvesting methods (e.g. walk-over slash, or cable or 'shovel' logging), planning the layout of extraction tracks, timing operations to avoid high soil moisture, and protection of soils with matting or cording. Modern harvesting vehicles and accumulated operational knowledge have combined to greatly reduce soil impacts (e.g. reducing ground pressure by using rubber-tyred vehicles).

In all states and territories, measures to protect soil physical properties were in place for the reporting period. In some jurisdictions, these have been implemented in multiple-use public forests for many years, but only in Victoria, South Australia and Tasmania are these measures applied to all wood harvesting operations, regardless of tenure.

A range of measures are undertaken to protect soil physical properties, varying with the nature of the soils, the seasonal conditions and the type of harvesting activities being undertaken. Measures undertaken to protect soil physical properties include:

- controls on placement of felled trees and log extraction operations in or near streams or riparian areas
- methods of construction and maintenance of extraction and other temporary tracks, including cording and matting
- size, placement and management of log dumps and log landings for storage, and loading of logs for transport
- selection of harvesting machines, including whether machines have tracks, tyres or chains
- machinery restrictions on slopes, and restrictions on clearing steep slopes for plantations
- wet-weather shutdowns.

Acid sulphate soils could cause problems for forest ecosystems if such soils were exposed through excavation activities. However, forestry operations are unlikely to create such problems because they do not generally involve substantial excavation.

Instruments that address risks to soil physical properties

The extent to which a regulatory framework requires the maintenance of soil physical properties is rated according to the five categories used in previous SOFRs. These categories are detailed in Table 4.9, and range from Category 1 (for regulatory instruments that take into account risks to soil physical properties from site factors, management factors and vehicle factors associated with disturbance activities) to Category 5 (for instruments that do not mention the need to address risks to soil physical properties). The extent to which the risks to soil physical properties are addressed by a state or territory's legally binding instruments (such as Acts) and non-legally binding instruments (such as codes of practice, guidelines and forest management plans) is assessed against these categories in Table 4.10.

The data in Table 4.10 show that there are regulatory instruments in place to manage risks to soil physical properties to varying degrees in all jurisdictions and for all tenures for which this was reported. Most of these

Table 4.9: Categories of the extent to which a regulatory framework requires the maintenance of soil physical properties

Category	Category description
1	The instruments require the following components to be taken into account in addressing the risk to soil physical properties from disturbance activities: • site factors, including the soil properties of moisture content, organic matter content, soil type and texture; presence of litter, trash or slash; slope; and rainfall distribution and intensity • management factors, including timing of operations (season), harvesting system, harvesting pattern and slash distribution • vehicle factors, including machine configuration, vehicle weight, dynamic load, tyre size, tyre inflation pressure, wheel slip, tracks or wheels, vibration, number of passes, vehicle speed, area affected, and whether logs are dragged, lifted or carried.
2	The instruments address most of the components listed in category 1, and those not addressed are associated with low risks to soil physical properties for the particular disturbance activity and geographical setting.
3	The instruments address most of the components listed in category 1 but do not specify all aspects or are limited in their application.
4	The instruments mention the need to address risks to soil physical properties when conducting disturbance activities but do not specify the components listed in category 1.
5	The instruments do not mention the need to address risks to soil physical properties.

Source: SOFR 2008.

Table 4.10: Assessed extent to which legally and non-legally binding instruments address the risk to soil physical properties from forest operations, road and trail works, fire management and recreation activities

Instrument	Tenure	ACT	NSW	NT	Qld	SA	Tas.	Vic.	WA
Legally binding	Multiple-use public forests	5	1–2	1–5[a]	2	4	1	1	4
	Public nature conservation reserves	5	4	2	n.r.	4	1–2	1	4
	Leasehold land	n.r.	n.r.	n.r.	2	4	n.r.	n.r.	n.r.
Non-legally binding	Multiple-use public forests	1	2	5	2	1	1	3	1
	Nature conservation reserves	1	5	5	n.r.	n.r.	1–2	3	4
	Leasehold land	n.r.	n.r.	n.r.	2	1	n.r.	n.r.	n.r.

n.r., not reported.

[a] Extent to which instruments address the risk to soil physical properties varies between 1 and 5 for different management disturbance activities.

Notes:

Data are for 2011–16 for ACT, NSW, NT, Qld, SA and Tas.; data are from SOFR 2013 for Vic., and are updated from SOFR 2013 for WA.

The extent to which instruments address the risk to soil physical properties varies between category 1 (highest rating) and category 5 (lowest rating): see Table 4.9. Each rating is an assessment by the relevant jurisdiction.

Source: State and territory agencies.

This table, together with other data for Indicator 4.1c, is available in Microsoft Excel via www.doi.org/10.25814/5bda9272d76d7

instruments rate highly for the number of factors that must be taken into account. The rating shown for multiple-use public forests in Western Australia has been refined since that reported in SOFR 2013 based on further assessment of the regulatory instruments. Ratings have not changed or were not reported in SOFR 2013 for other jurisdictions.

Operational-level requirements or guidance to manage impacts on soil physical properties are described in various legally and non-legally binding instruments, particularly codes of practice, at state or territory and regional levels. Legally binding instruments relating to soil physical properties are in place in New South Wales, the Northern Territory, South Australia, Tasmania, Victoria, Queensland and Western Australia.

The general principles of the codes of practice are that any potential damage is to be mitigated, logs are to be removed in a manner and by methods that do not result in significant soil disturbance, and damage caused by the forest management operation, including damage to soil physical properties, is to be repaired. Aspects that are covered in codes of forest practice include assessment and management of soil compaction, mitigating soil movement, creation and management of filter strips or buffers, and consideration of appropriate machinery to protect soil physical properties.

The Queensland Parks and Wildlife Service (QPWS) is the custodian of state forests and timber reserves in Queensland, with timber harvesting carried out according to the *Code of Practice for Native Forest Timber Production on the QPWS Forest Estate 2014*[194] (DNPRSR 2014). The code requires timber production activities to be regulated to prevent or minimise deterioration of the soil physical properties. It prescribes soil assessments to identify soil compaction hazards, with compaction ratings providing guidance for managing high-risk areas through restrictions on operations, vehicle movements or wet-season harvesting. The Queensland code covering native forest on freehold land, *Managing a native forest practice – A self-assessable vegetation clearing code*[195] (DNRM 2014), sets a minimum acceptable environmental management standard to ensure that soils are protected from compaction or mass movement. The code requires that harvesting, thinning, or maintenance or use of roads and tracks does not occur on any area while the soil is saturated. The *Timber Plantation Operations Code of Practice for Queensland (2015)*[196] (Timber Queensland 2015) covers private plantation forests and includes soil protection as one of its goals. The code requires that modified harvesting methods are used when conventional harvest methods may threaten soil structure and stability or have the potential for adverse off-site effects.

In New South Wales, the Forestry Corporation of NSW undertakes comprehensive soil assessments in multiple-use public forests, as required by Integrated Forestry Operations Approvals (IFOAs), and implements mitigation measures to protect soil physical properties in high-risk areas. Wood harvesting on Crown Timber Lands other than State Forests or Timber Reserves that are categorised as 'Protected Lands' must comply with the provisions of the *Soil Conservation Act 1938* (NSW), and requires authorisation from the Commissioner for Soil Conservation. Forest practices codes for wood harvesting in native forests and plantations specify provisions to minimise soil disturbance (including compaction or rutting) during tracking, snigging, wet weather, and machine/vehicle movement, by placing restrictions on or managing harvesting systems and slash distribution. Bark is used to protect soil from loading machinery at log dumps. The *Code of Practice for Plantation Forestry: New South Wales*[197] (Forests NSW 2005) was assessed by Smethurst et al. (2012), who found that existing code content and implementation processes were generally adequate for protecting soil resources, but also recommended strengthening of provisions for inter-rotational slash management.

The NSW National Parks and Wildlife Service conducts few operations that are likely to affect soil physical properties, but revegetation and rehabilitation works are needed to address areas of previous disturbance. For example, revegetation works are required for disused roads and quarries; this work involves treatment of soil compaction, including seeding and spreading of topsoil. Detailed assessment of soil physical properties is required for geotechnical reports prepared when planning high-risk structures, when roads and walking tracks need to be realigned due to failing substrates, and where acid sulphate soils are likely to be present.

In Tasmania, forest activities carried out under the *Forest Practices Act 1985* require an assessment of risks to soil physical properties in accordance with the Forest Practices Code (most recently the *Forest Practices Code 2015*[198], FPA 2015b), irrespective of land tenure or forest type. The code requires forest operations to be planned according to soil load-bearing capacity. Ground-based harvesting equipment is not to be used on saturated soils, and careful attention is paid to the location, construction and post-harvesting treatment of snig tracks and landings to minimise soil compaction, puddling and mixing. In wet conditions, slash and branches are placed on extraction tracks to minimise soil damage.

In Northern Territory, the *Codes of Practice for Forestry Plantations 2004* (DRPI 2004) prescribes minimisation of adverse impacts on soils, such as compaction caused by machinery traffic during wet weather, and compaction during site preparation. A recent review of the code (Raison et al. 2012) recommended development of a new and more comprehensive code that provided guidance or reference to supporting documentation on how to achieve soil conservation goals, and noted a near-term need to develop harvesting plans for plantations. This code is being revised.

In Victoria, the *Code of Practice for Timber Production 2014* (DEPI 2014b) covers operations in native and plantation forests. It requires each harvesting operation to have a Forest

[194] www.npsr.qld.gov.au/managing/pdf/timber-production-qpws-estate.pdf

[195] pfsq.net/wp-content/2017/03/2015-managing-native-forest-practice-code.pdf

[196] www.timberqueensland.com.au/Docs/Growing-Processing/Timber-Plantation-Operations-Code-of-Practice-Version-1.pdf

[197] www.forestrycorporation.com.au/__data/assets/pdf_file/0010/457174/FNSW-ForestPracticesCode-2005.pdf

[198] www.fpa.tas.gov.au/fpa_services/planning_assistance/forest_practices_code

Coupe Plan that describes measures to protect and rehabilitate soils including, for example, measures to protect soil physical properties, such as that machinery must not enter any set filter strip, except at stream crossings. The potential for mass soil movement must be assessed when operating on steep soils, and necessary preventative actions undertaken; these include only felling trees out of filter strips, and using techniques such as cable logging rather than ground-based machinery on slopes greater than 30 degrees. The *Code of Practice for Bushfire Management on Public Land 2012* (DSE 2012) seeks to protect soil by measures that minimise damage to soil physical properties, or that promote stabilisation of bare earth following disturbance.

Harvesting wood from native forests is not permitted in the Australian Capital Territory. Plantation forestry in the Australian Capital Territory achieves soil protection through the *ACT Code of Forest Practice* (Environment ACT 2005)[199] and related guidelines (Smethurst et al. 2012). All operations carried out within a plantation need to be conducted according to an operational plan based on the *ACT Code of Forest Practice*. The code recognises the importance of protection of soil from degrading processes, including compaction, and loss of nutrients, organic matter, or structure. It prescribes on-site slash retention rather than slash burning. The code also requires that soil compaction and rutting depth are considered when assessing the suitability of machinery for operations.

Western Australia's *Forest Management Plan 2014–2023* (CCWA 2013) and earlier plans prescribe activities to protect soil physical properties from threats of compaction and rutting as a result of use of heavy vehicles or inadequate rehabilitation of damaged soil. The Forest Products Commission is bound by the *Code of Practice for Timber Plantations in Western Australia* (FIFWA 2014), which requires that soil compaction be minimised when conducting operations, including by regulating any disturbance affecting soil stability, and applying wet weather restrictions to minimise soil damage.

In addition to the *Forest Management Plan*, there are other instruments in Western Australia that assist in the protection of soil physical properties. The *Soil and Water Conservation Guidelines 2009* (DEC 2009c) provides a number of guiding principles, supported by relevant strategies, for the conservation of soil values. The *Manual of Procedures for the Management of Soils Associated with Timber Harvesting in Native Forests 2010* (DPAW 2010) provides a guide for managing soil properties, including a trafficability index that defines soil management risk periods and permissible activities in relation to soil moisture. The manual also specifies the additional planning and approval requirements for operations during the wetter part of the year, and includes definitions of soil disturbance categories and procedures for assessing and monitoring soil disturbance. The *Code of Practice for Fire Management 2008*[200] (DEC 2008) requires managing fires to protect soil stability, physical and chemical properties and soil rehabilitation following disturbance.

In South Australia, legally binding instruments such as the *Environment Protection Act 1993* and the *Natural Resources Management Act 2004* mention the need to address risks to soil physical properties when conducting disturbance activities on forest land; however, they do not specify individual components of soil physical properties. Under the South Australian *Forestry Regulations 2013*, it is prohibited to intentionally destroy, damage or disturb, remove any soil, from a forest reserve. The importance of minimising soil disturbance and soil compaction are emphasized in the *Guidelines for Plantation Forestry in South Australia 2009*[201]. The planning of harvesting operations must consider site characteristics (slope, soil type and water courses), season, extraction and haulage routes, load sizes, and machinery movements, to minimise soil damage and subsequent impact on water run-off. The guidelines require land-use options and management practices to be selected based on the Plantation Forestry Land Capability Classification System, which in turn is based on soil physical properties such as drainage, texture, structure and depth. As an example, risks associated with poorly drained soils are managed by mounding planting lines, and restricting harvesting operations when soil is saturated.


Tim Clancy

Mounded planting lines to reduce water run-off in a plantation, Tasmania.

[199] www.environment.act.gov.au/parks-conservation/management_of_the_commercial_pine_plantation_estate

[200] www.dpaw.wa.gov.au/images/documents/fire/fms-code-of-practice.pdf

[201] www.pir.sa.gov.au/__data/assets/pdf_file/0011/254765/guidelines_for_plantation_forestry_in_sa_web.pdf

Assessment of risk to soil physical properties

The extent to which soil physical properties are assessed in planning processes across jurisdictions is rated according to the four categories used in previous SOFRs. These categories are detailed in Table 4.11, and range from Category 1 (for a soil physical properties risk assessment system that takes into account site factors, management factors and vehicle factors) to Category 4 (for an ad hoc risk assessment system that does not take into account any factors relevant to soil physical properties).

Table 4.12 shows that, for the jurisdictions for which data were provided, the codes of practice and other instruments in place generally require assessment of risks to soil physical properties. Assessment of the potential risk to soil physical properties is usually covered in the codes of practice and other instruments, and carried out by forest managers, in conjunction with an assessment of soil erosion hazard, using the various processes reported in Indicator 4.1b. Other than wood harvesting, the areas of which are reported in Indicator 2.1a, the area of multiple-use public forest for which disturbance activities are planned is not reported for most jurisdictions.

Table 4.11: Categories of the extent to which soil physical properties are assessed in planning processes

Category	Category description
1	The soil physical properties risk assessment system takes into account all the following factors: • site factors, including the soil properties of moisture content, organic matter content, soil type and texture; presence of litter, trash or slash; slope; and rainfall distribution and intensity. • management factors, including timing of operations (season), harvesting system, harvesting pattern and slash distribution. • vehicle factors, including machine configuration, vehicle weight, dynamic load, tyre size, tyre inflation pressure, wheel slip, tracks or wheels, vibration, number of passes, vehicle speed, area affected, and whether logs are dragged, lifted or carried.
2	The risk assessment system takes into account most of the components listed in category 1, and those not addressed are associated with low risks to soil physical properties for the particular disturbance activity and geographical setting.
3	The risk assessment system takes into account some of the factors listed in category 1 or only partly accounts for these factors.
4	The risk assessment system is ad hoc and/or does not take into account any of the factors listed in category 1.

Source: SOFR 2008.

Table 4.12: Area of multiple-use public forest where disturbance activities were planned, proportion assessed for risk to soil physical properties, and assessed category

Disturbance activity	Metric	ACT[a]	NSW	NT[a]	Qld	SA[a]	Tas.	Vic.	WA
Native forest harvesting and silviculture	Area (hectares)	n.a.	17,000–32,000	n.a.	n.r.	n.a.	n.a	n.r.	n.r.
	Assessed for risk to soil properties (%)	n.a.	100	n.a.	100	n.a.	100	100	100
	Assessment category[b]	n.a.	1	n.a.	2	n.a.	1	3	3
Plantation operations	Area (hectares)	627	7,000–10,000	n.a.	n.r.	n.r.	n.r.	n.r.	n.r.
	Assessed for risk to soil properties (%)	100	100	n.a.	n.a.	100	100	90	n.r.
	Assessment category[b]	1	1	n.a.	n.a.	1	1	2	n.r.
Road construction and maintenance	Area (hectares)	n.r.	n.r.	n.a.	n.r.	n.r.	n.r.	n.r.	n.r.
	Assessed for risk to soil properties (%)	n.a.	100	n.a.	n.a.	100	100	60	100
	Assessment category[b]	n.a.	1	n.a.	n.a.	3	1–2	2	3
Fire management	Area (hectares)	n.r.	20,000–40,000	n.a.	n.r.	n.r.	n.r.	n.r.	n.r.
	Assessed for risk to soil properties (%)	n.a.	100	n.a.	n.a.	100	100	90	n.r.
	Assessment category[b]	n.a.	1	n.a	n.a.	3	1-2	2	n.r.

n.a., not applicable; n.r., not reported

[a] South Australia & ACT do not harvest native forest; there is no multiple-use forest in the NT.

[b] The extent to which soil physical properties are addressed during planning processes varies between 1 (highest rating) and 4 (lowest rating): see Table 4.11. Each rating is an assessment by the relevant jurisdiction.

Note: Data for 2011–16 except that data for Tas., Vic. and WA are from SOFR 2013. NSW figures are the range of annual areas across the five-year reporting period. Areas harvested are reported in indicator 2.1a.

Source: State and territory agencies.

This table, together with other data for Indicator 4.1c, is available in Microsoft Excel via www.doi.org/10.25814/5bda9272d76d7

Knowledge base on soil physical properties

Improving soil data for plantation planning and management is a priority outlined in the 2010 Research, Development and Extension (RD&E) Strategy for the forest and wood products sector (FWPA 2010). This priority aligns with Australia's first National Soil Research, Development and Extension Strategy (Commonwealth of Australia 2014) which also sets a priority to 'provide improved data for land use planning'.

The coverage and level of detail of mapping of soils in forested areas varies across states and territories. For example, major areas of state forest in northern Tasmania have been mapped at 1:250,000 scale, and 95 soil types with differing properties and erosion risks have been identified throughout the state, mostly in state forests. New maps of soil texture at a regional scale were developed for the whole of Victoria by the Victorian Department of Economic Development, Jobs, Transport and Resources in 2014. A new edition of *Soil groups of Western Australia* was released in 2013 (Schoknecht and Pathan 2013). Areas containing acid sulphate soils have been mapped for the entire NSW coastline at a scale of 1:25,000 (NSW OEH 2016a).

In South Australia, regional natural resource management plans include a summary of threats and issues relating to soil physical conditions in multiple-use forest, nature conservation reserves and other crown land. The Soil and Land Program of the Department of Environment, Water and Natural Resources has developed models that assess the potential of land for specific uses including forestry, using soil and land attribute spatial datasets. Comprehensive soil and land mapping information for South Australia was delivered through the State Land and Soil Mapping Program (1986–2012)[202].

In Western Australia, the knowledge base on the potential impacts on soil physical properties of various forest activities, including machinery disturbance, improved during the reporting period. Heavy machinery used in timber harvesting can cause severe soil rutting and compaction, with the impact exacerbated in wet conditions (Whitford 2011). In the forests of south-western Western Australia, soil compaction on log extraction tracks is related to log load, initial soil bulk density, and gravel content. Compaction increases as the total load of logs hauled over the tracks increases. Soils with a high initial bulk density and high gravel content were less compacted during timber harvesting (Whitford 2012). Primary and secondary extraction tracks were more compacted than tertiary extraction tracks, and significantly more compacted than the general harvested area; soil compaction is known to persist for decades after timber harvesting unless treated. Limits for soil disturbance, and criteria for harvesting operations on moist soil in jarrah forest in south-west WA, were revised based on these findings and incorporated into the *Forest Management Plan 2014–2023* (CCWA 2013) and associated guidelines.

Practices to protect soil during wood harvesting and other operations have changed considerably during the past decade in the forests of south-western Western Australia (CCWA 2013). Cording or corduroy[203] is used to disperse the load of heavy machinery over a larger area, and to significantly reduce compaction, rutting and associated soil mixing (Whitford 2011). Focusing all traffic onto as few tracks as possible, and reusing compacted extraction tracks that remain from any previous harvesting, are the most effective means of reducing the impact of timber harvesting on soils (Whitford 2012).

High-severity fires can induce important changes in soil structure and aggregate stability, due to loss of organic matter, and changes in water repellency and other physico-chemical properties. During wildfire, organic compounds vaporise and move downwards through the soil profile, then condense to form a hydrophobic layer or coating around soil particles (Tulau 2015). A recent study by Heath et al. (2015) in two catchments in the Blue Mountains, New South Wales, found that burn severity had a significant effect on soil carbon levels and topsoil water repellency. Total soil carbon and water repellency were highest in areas affected by burns of low severity, decreased with burns of moderate and high severities, and increased again with burns of very high severity.

Knowledge of risks to soil properties is progressively incorporated into state and territory instruments, and disseminated to the industry in various ways. For example, in Tasmania dissemination of knowledge occurs through the Forest Practices Authority, which provides landowners and managers with access to soil management resource materials, including manuals and fact sheets. Combined with ongoing research and training and the experience of forest managers, these resources help to identify and map soils, and enable assessment and management of risks arising from the interactions of factors such as slope, climate, soil type, rainfall, stream management and vegetation cover.

[202] www.environment.sa.gov.au/Knowledge_Bank/Information_data/soil-and-land/mapping-soil-and-land

[203] Corduroy is round or split log material that is laid across extraction tracks (snig tracks) in a close and continuous layer, or placed across landings, so as to distribute machine loads over a larger area.

Indicator 4.1d

Management of the risk to water quantity from forests

Rationale

This indicator measures the extent to which the risk to water quantity has been explicitly identified and addressed in forest management. Water quantity is important for ecosystem health and water supply for human use.

Key points

- All jurisdictions where native forest harvesting is permitted have regulatory instruments, such as codes of practice or management guidelines, to manage activities related to harvesting that could affect water yields from forests.
- Practices such as selecting the location of forest to be harvested, limiting the proportion of catchments to be harvested in a year, and thinning to increase water yield, are implemented to manage potential impacts of forestry operations on water quantity.
- Understanding of the impacts of forest type, age, growth rate and tree density on water yield continues to improve, but the ability to predict changes in water yield in specific circumstances is less well developed.
- Water use by tree plantations was considered a significant concern when substantial areas of new plantations were being established at a time that coincided with the 'millennium drought' (1996–2010 in eastern Australia). That concern waned in most jurisdictions when plantation expansion ceased in 2008 and more typical rainfall patterns returned.

Large areas of forested land are used to provide reliable and clean supplies of drinking water for human consumption, as well as for irrigation and industrial uses. The quantity of water available in streams and rivers flowing from forested catchments depends on the combination of rainfall, water interception and use by the forest vegetation, run-off, and entry to groundwater systems. Rainfall varies seasonally and across longer periods, while the amount of water used by a forest stand depends on its age, tree density, species mix and growth rate. In general, forested catchments provide higher quality water supplies with a lower risk of variation in water quantity and quality than do catchments with other (non-forest) land uses.

Management practices likely to affect water yields in forested catchments include the timing, scale and spacing of wood harvesting; thinning of regrowth forest; fire management; control of woody weeds; modifications to rotation lengths of growing forests or plantations; and land-use change (e.g. forest clearing for agriculture, or reforestation of former agricultural land). Harvesting wood over a short period from a large proportion of a catchment would change the forest age-class structure significantly, and where a large proportion of the catchment water yield is utilised could affect water supply. However, most water supply catchments are sufficiently large, and the proportion affected from year to year by forest disturbance such as wood harvesting is relatively small, that effects on water supply are typically not significant.

Major bushfire events can influence water yields by changing the age-class structure of native forests, as stand age and leaf area are major determinants of forest water use. Run-off can be high immediately after bushfire as regeneration develops, and low from the subsequent regrowth forest stands, before increasing again as stands mature. The magnitude of these changes depends on the proportion of a catchment that is forested, soil types, the proportion of forest that is burnt, and the intensity of the fire; much smaller effects are likely in mixed-species catchments subject to non-stand-replacing fires.

Instruments in place that address the risk to water quantity

Regulatory instruments specify measures to be implemented to maintain stream flows and water quantity in particular locations. These instruments also provide benchmarks against which the management of water quantity can be assessed. Legally binding instruments include Acts and licences, whereas non-legally binding instruments include codes of practice, guidelines and forest management plans.

The extent to which a regulatory framework aims to maintain water quantity after disturbances associated with forest management is rated according to the five categories used in previous SOFRs. These categories are detailed in Table 4.13, and range from Category 1 (for regulatory instruments that take into account a variety of risks to water quantity) to Category 5 (for instruments that do not mention the need to address risks to water quantity). The extent to which the risks to water quantity posed by forest management activities in multiple-use public forests are addressed by a state or territory's legally binding instruments and non-legally binding instruments is assessed against these categories in Table 4.14.

Compared with protection of water quality, which is a major concern and focus of legislative and regulatory instruments in all jurisdictions and for all tenures (see Indicator 4.1a), protection of water quantity is only of concern where forest establishment or management might affect water supply. Table 4.14 accordingly shows lower ratings for most jurisdictions than Table 4.16, which deals with water quality instruments. The ratings shown for New South Wales and South Australia have been refined since being reported in SOFR 2013, based on further assessment of the regulatory instruments. Ratings have not changed or were not reported in SOFR 2013 for other jurisdictions.

In the Australian Capital Territory, the *Planning and Development Act 2007* requires development proposals likely to have a significant adverse impact on domestic water supply catchments, which are forested and managed under a reserve management plan, to have environmental impact statements.

Table 4.13: Categories of the extent to which regulatory frameworks aim to maintain water quantity after disturbances associated with forest management

Category	Category description
1	The instruments require the following components to be taken into account in addressing the risk to water quantity posed by forest management-related disturbance activities: • local and regional requirements relating to water yield, and the sensitivity of the water supply system to changes in water yield • age structure of stands in forested catchments • the conversion of mature stands to regrowth • rotation lengths • stand density.
2	The instruments address most of the components listed in category 1, and those not addressed are associated with a low risk to water quantity for the particular disturbance activity and geographical setting.
3	The instruments address most of the components listed in category 1 but do not specify all aspects or are limited in their application.
4	The instruments mention the need to address risks to water quantity when conducting disturbance activities but do not specify the components listed in category 1.
5	The instruments do not mention the need to address risks to water quantity.

Source: SOFR 2008.

Table 4.14: Assessed extent to which legally binding and non-legally binding instruments address the risk to water quantity from forest management activities in multiple-use public forests

Type of instrument	ACT	NSW	NT	Qld	SA	Tas.	Vic.	WA
Legally binding	n.a.	4	n.a.	5	1,5[a]	1	2	4
Non-legally binding	n.a.	3	n.a.	5	4,5[b]	1	2	5

n.a., data not available

[a] Rating 1 for plantation operations; 5 for other activities.

[b] Rating 4 for plantation operations; 5 for other activities.

Note: The assessed extent to which instruments address the risk to water quality varies between 1 (highest rating) and 5 (lowest rating): see Table 4.13. Each rating is an assessment by the relevant jurisdiction.

Sources: Data for Tas. from FPA (2017a), and for Qld and SA are for 2016. Data for Vic. and WA are from SOFR 2013. Data for NSW from Forestry Corporation NSW.

This table, together with other data for Indicator 4.1d, is available in Microsoft Excel via www.doi.org/10.25814/5bda9272d76d7

Maintaining appropriate levels of water yield and flow duration in catchments is one of the aims of NSW Regional Forest Agreements (State of NSW 1999; 2000; 2001). In New South Wales, Integrated Forestry Operations Approvals (IFOAs)[204] apply to anyone carrying out forestry operations on State forests and other Crown-timber lands. Under the conditions of IFOAs, wood harvesting operations in public multiple-use native forests are required to be dispersed in space and time; this mitigates environmental impacts, including potential effects on water quantity. Of a total of 2.0 million hectares of multiple-use public forests in New South Wales, approximately 30 thousand hectares (1.5%) are harvested annually, in a mosaic across the estate (FCNSW 2016d); that small proportion distributed across the estate is unlikely to have a significant effect on water quantity in any one catchment.

Water supply from forested catchments is generally not a limiting factor in Queensland. The *Forestry Act 1959* and native forest codes of practice[205] refer to protection of watershed values. Native forest practices address relevant catchment goals during preparation of Operational Harvesting Plans. Forest products operations are dispersed in nature and occur over only a small proportion of any regulated catchment. Selective harvesting has only a limited impact on canopy cover, and thus on water use by the forest. As a result, forest operations do not have significant impacts on water flows at the catchment scale.

With respect to water quantity, water resources in South Australia are protected and managed by being 'prescribed' under the *Natural Resources Management Act 2004* (NRM Act). The NRM Act was amended by the *Natural Resources Management (Commercial Forests) Amendment Act 2011* to give South Australia state-wide forest water legislation. Furthermore, the *Natural Resources Management (Review) Amendment Act 2013* permits South Australian watercourse water and surface water to be treated as one entity, and interconnected water resources to be managed together in appropriate cases.

Regional Natural Resources Management (NRM) boards in South Australia develop a Water Allocation Plan (WAP) for each prescribed water resource. WAPs require forest plantations to be formally assessed for risk to water quantity. WAPs for the Eastern Mount Lofty Ranges, Western Mount Lofty Ranges and Lower Limestone Coast were implemented in 2013. The Lower Limestone Coast Prescribed Wells Area WAP includes a forest water licensing system. Around 165 commercial forestry licences were issued when that plan was implemented. The plan also provides for water allocations to be reduced where unacceptable impacts are occurring, including impacts of commercial forest management. Some of these allocation reductions have already begun in two water management areas, requiring 51% and 44% allocation reductions over eight years. Activities affecting water in the Eastern Mount Lofty Ranges and Western Mount Lofty Ranges are managed under a permit system, however the policies regarding harvesting and replanting differ. The *Forestry Regulations 2013* allow ForestrySA to protect water resources in state forest reserves for the benefit of local communities.

In Tasmania, both the previous *Forest Practices Code 2000* and the current *Forest Practices Code 2015*[206] restrict wood harvesting to no more than 5% of the area of any town water supply catchment in any given year.

In Victoria, Melbourne's water supply catchments include large areas of national parks and some State forests. Harvesting currently takes place in a very small proportion (0.14%) of the area of Melbourne's water supply catchments, and Melbourne Water does not collect water from tributaries of the Yarra River when timber harvesting occurs in upstream catchments; this harvesting also has a minimal impact on overall water yield[207]. Across Victoria, and as set out in the *Timber Allocation (Amendment) Order 2014*, within a five-year period VicForests only harvests 6% of the area of ash forests and 4% of the area of mixed forests available for harvesting, which also minimises the impact on the volume of water generated from the forest.

In Western Australia, the *Forest Management Plan 2014–2023*[208] has been adopted for the south-west forest region. This Forest Management Plan (FMP) continues the approach to protecting water resources of the previous plan. The new FMP includes activities to manage threats of excessive extraction of water by native vegetation and plantations and for human use, and to manage declining rainfall and consequent reductions in groundwater levels and stream flows, damage to stream beds and banks, and changes in the composition, structure and density of riparian vegetation. The new FMP also provides for the preparation of catchment management plans that apply silviculture treatments such as thinning to increase the flow of water to surface and groundwater reservoirs in areas such as over-stocked regrowth forests.

The Northern Territory also contains a number of stream-gauging stations that collect data on water flow rates.

Changes to the water quantity knowledge base

Native forests

Knowledge of the effects of forest operations on water quantity is well developed, particularly in New South Wales, South Australia, Victoria and Western Australia. Capacity to model the effects of wood harvesting, bushfires, forest type, forest age, and climatic variation on catchment water yield improved during the reporting period, and continues to be a key area of research.

[204] www.epa.nsw.gov.au/your-environment/native-forestry/integrated-forestry-operations-approvals/

[205] publications.qld.gov.au/dataset/self-assessable-vegetation-clearing-codes/resource/a73f5b44-008c-4f92-8644-f92e6caf6592

[206] publications.qld.gov.au/dataset/self-assessable-vegetation-clearing-codes/resource/a73f5b44-008c-4f92-8644-f92e6caf6592

[207] www.vicforests.com.au/static/uploads/files/fs-water-web-wfrouxwzendz.pdf

[208] www.dpaw.wa.gov.au/images/documents/conservation-management/forests/FMP/20130282_WEB_FOREST_MGT_PLAN_WEB.pdf

The Black Saturday bushfires of February 2009 burnt nine catchments north and east of Melbourne, Victoria. A total of 28% of the area of the forested catchments that supply water to the city of Melbourne was affected, with 11% of the area of these catchments severely burnt by intense fire. Feikema et al. (2013) predicted, under average rainfall conditions, a maximum annual reduction in long-term streamflow in the fire-affected water supply catchments of 3.0–6.1%, and a total reduction in post-fire streamflow after 100 years of 1.4–2.8%. These values are low due to the relatively small proportion of the catchments affected by severe fire, and the relatively low tree mortality within these fire areas. Benyon and Lane (2013) found that long-term water yields were expected to decrease in catchments where densities of regenerating seedlings were high, but that there might be long-term increases in water yields in areas with little or no eucalypt regeneration. Removal of the understorey, or suppression of understorey regrowth by an intact overstorey, might result in water yield increases that persist for a decade or more. Thinning of regenerating native forest is another option for increasing water yields after fire (Case Study 4.2).

New South Wales has a well-developed knowledge-base on forest water yields, based on long-term catchment hydrology research. Webb and Jarrett (2013) detected an increase in total streamflow following bushfire and/or integrated harvesting at various intervals in five catchments containing mixed-species eucalypt forest in south-eastern NSW, with a minor reduction in streamflow observed in only two catchments. Catchment-scale hydrological responses in mixed-species eucalypt forests differ from those in ash forests, which have a longer recovery period through seedling regeneration.

The severe 2001–02 bushfires in drinking-water catchments in the outer Sydney Basin led to little or no substantial medium-term impact on water yield in the subsequent 10 years (Heath et al. 2014). These catchments are dominated by vegetation communities that regenerate by resprouting, and that therefore have greater hydrological resilience to severe bushfire than communities dominated by vegetation that only regenerates from seed. On the other hand, Nolan et al. (2015) found different hydrological responses in similar forests following bushfires in 2006 and 2009 in south-eastern Australia, with streamflow reduction over 1–4 years post-fire, due both to climate and to fire effects on vegetation. The reduction in mean annual stream flow was much less in a very wet year, and streamflow recovered to the pre-fire level within 8–12 years after the fire. Finally, long-term hydrological studies in three types of mixed-species eucalypt forest in New South Wales found an increase in water yield after harvesting, dependent on the proportion of the catchment area harvested (Webb et al. 2012a). The increase persisted for at least three years, after which water yield returned to pre-harvest levels, before progressively declining in regenerating forest in some catchments by up to 20% of the pre-harvest water yield; this reduction was generally temporary and was related to changes in forest species composition, basal area and stocking rates. Overall, this research supports the conclusion of Bren et al. (2013) for the Murray–Darling Basin catchments, that it is possible to manage native forests to achieve an optimal level of wood and water production through a combination of carefully scheduled harvesting and fire management.

Declining rainfall in Western Australia is leading to a disconnection between groundwater and surface water systems in some jarrah forest catchments (Kinal and Stoneman 2012). Kinal and Stoneman (2011) found that vegetation thinning may be an appropriate management action to reduce the decline in, or increase the amount of, streamflow within the jarrah catchments. New provisions 'silviculture for ecosystem health' and 'silviculture for water production' were therefore incorporated into the *Forest Management Plan 2014–2023* (CCWA 2013), with the effectiveness of silviculture for water production to be measured as a key performance indicator.

In Queensland, there is a reasonable knowledge of impacts of activities on water quantity. However, the need for improved knowledge to assist managers with some risk factors has been identified. Clearing of woody vegetation (including forest) in Queensland increased from less than 100 thousand hectares in 2012–13 to 395 thousand hectares in 2015–16 (DSITI 2017). Queensland's *State of the Environment report 2016*[209] reported no significant or widespread hydrological (water quantity) impacts, potentially because this clearing is dispersed across the state or does not occur in urban drinking-water catchments.

In South Australia, the water-quantity knowledge base is well-developed. Water Allocation Plans are developed and reviewed. A mid-term review of the condition of the water resources managed by the Lower Limestone Coast Prescribed Wells Area WAP is due in 2019. Groundwater levels are monitored by a network of observation wells, and an annual report on the condition of the resource is published by SA's WaterConnect[210]. A project is underway to validate existing forest water models, review groundwater models, and undertake management scenarios for the Wattle Range in the Lower Limestone Coast area.

Plantations

Water use by forest plantations was considered a significant concern when substantial areas of new plantations were being established, which coincided with the 'millennium drought' (1997–2009; Ryan 2013). That concern decreased when plantation expansion ceased in 2008 and more typical rainfall patterns returned. Some of the relevant research is summarised here.

Development of large-scale plantation forestry was included as one of the land-use changes to be considered by the Intergovernmental Agreement on a National Water Initiative[211] (NWI), which provided a framework for considering the impacts of activities that could intercept water. As each jurisdiction in Australia attempts to implement the 'interception' requirements of the NWI, water balance models will be required to allow accurate assessments of plantation water use at a catchment scale (see Webb 2009).

[209] www.ehp.qld.gov.au/state-of-the-environment/

[210] www.waterconnect.sa.gov.au/Pages/Home.aspx

[211] www.agriculture.gov.au/SiteCollectionDocuments/water/Intergovernmental-Agreement-on-a-national-water-initiative.pdf

Case study 4.2: The impact of strip thinning on water yield in Crotty Creek catchment, Central Highlands of Victoria

During the drought years of 1997 to 2009, inflows to catchments located high in the Yarra Ranges to the north-east of Melbourne decreased by 60% compared to historic values. In addition, bushfires reduced mean forest age in some catchments, potentially increasing forest water use for a period of time. The bushfires of 2003 and 2006–07 are expected to lead to a reduction in streamflow of 81 gigalitres per year from the pre-fire condition, due to the large-scale regeneration of alpine ash (*Eucalyptus delegatensis*) forests in some catchments. In addition, extrapolating across the catchments predicts that the 2009 bushfires will lead to a 3% reduction in water inflows to reservoirs over the next 50 years.

This situation has led to a need for changes in land-use or forest management aimed at reducing vegetation water use. One of many options to increase water supply is thinning the regenerating forests, which is a feasible approach for producing both water and wood (Ryan 2013). Thinning of regrowth forests from the age of 20–50 years can generally be undertaken at low cost, and sometimes even with a positive financial return, while simultaneously achieving water production objectives by increasing water yields. A low level of regeneration in the thinned areas will assist in maintaining on-going water yields.

This scenario was tested in a case study conducted in 1939 mountain ash (*E. regnans*) regrowth forests in the Crotty Creek catchment, in the Central Highlands of Victoria. Fifty percent of trees were removed in strips 35 metres wide.

Water yield within the thinned catchment is expected to be 40% greater than that from unthinned catchments, with the gain dropping to 16% within 11–15 years as the remaining trees begin to occupy the openings, and the understorey colonises the thinned sites.

Source: Ryan (2013).

Strip thinning trial, Crotty Creek, Central Highlands, Victoria.

Accurate assessments of plantation water use at a catchment scale are required to develop water-balance models in plantations. Roberts et al. (2015) measured all components of plantation water use (canopy interception, soil evaporation, and transpiration) over a period of 3 years in a range of shining gum (*Eucalyptus nitens*) plantation sites in Tasmania, and developed a system to predict water use by plantations of this species from simple plantation inventory measurements. Plantation water use ranged between 500 and 1100 mm per year. Similar values were reported by Benyon and Doody (2014) for blue gum (*E. globulus*) plantations in South Australia. The impact on water availability of projected new plantations across the central north and north-east of Tasmania was modelled by Post et al. (2012). They found that runoff decreased in proportion to the increase in forest cover, but that, while decreases could be significant locally, decreases across the whole of the state would be less than 1%, both annually and for each season.

Zhang et al. (2011, 2012) evaluated plantation impacts on streamflow in 15 catchments across southern Australia using 20–35 years of continuous daily streamflow data and records of plantation management practices. There was a negative relationship between streamflow and plantation area in a catchment; an increase in catchment area occupied by plantations is likely to result in a reduction in streamflow compared to unforested controls. However, in Australia, forest plantations occupy only a small percentage of the catchments in which they occur (Downham and Gavran 2017). Because rainfall and hydrological factors are highly variable, it is difficult to detect the impact of plantations on water yields if the plantations occupy less than 15–20% of a catchment, and those proportions are only likely to be reached in small headwater catchments (Parsons et al. 2007). Zhang et al. (2011, 2012) also found that reductions in streamflow with plantation expansion were relatively uniform in catchments with perennial streamflow, and larger in catchments with ephemeral streamflow.

Barlow et al. (2013) used plantation data for the period 1975–2008 to model the impacts of forest plantations on streamflow in catchments in south-west Victoria, where significant expansion in plantation forestry has taken place. Introduction of plantation history into the model reduced predicted streamflow, but the impact of future plantation expansion on streamflow was predicted to vary across the landscape due to the variable effects of climate, soil properties, slope, and local hydrology.

O'Grady et al. (2012) modelled the impact on catchment water balance of the expansion of African mahogany (*Khaya senegalensis*) plantations in the Daly region of the Northern Territory. The model predicted that the projected plantation expansion would have a small impact on catchment water resources, mainly because the plantations have similar water use to the local native woodlands.

Lake Eildon, Victoria.

Indicator 4.1e

Management of the risks to water quality in forests

Rationale

This indicator measures the extent to which the risk to water quality has been explicitly identified and addressed in forest management. Water quality is important for forest ecosystem health and water supply for human use.

Key points

- The risks that forest management activities pose to water quality are well understood, as are ways to mitigate those risks. The knowledge base about how to mitigate those risks improved during the reporting period.
- All states and territories have legislation, licences, codes of forest practice or best management practice manuals that mandate or guide practices to be carried out to maintain water quality. These instruments specify a range of factors that must be taken into account.
- These instruments also contain comprehensive requirements to assess the risk to water quality when planning wood harvesting operations. This reflects water quality being a major concern and focus of legislative and regulatory instruments.
- Compliance with mitigation measures to protect water quality is assessed in all states and territories, and is generally high for wood harvesting operations.

This indicator reports on the mitigation measures that are in place to protect water quality during forest management activities. The focus of reporting is on multiple-use public forest and public nature conservation reserves, with data generally not available for other tenures in most states and territories.

Water quality

Large areas of forest land supply water for human consumption, irrigated agriculture and industrial uses, with the forest soil and litter acting as a water store and filter that improves water quality. In general, forested catchments maintain water quantity and quality better than do catchments with other (non-forest) land uses. However, forest management activities and other disturbances such as fire can affect water quality unless planned, managed or mitigated appropriately, for example through measures such as road and track drainage, and maintaining vegetated streamside (riparian) buffer zones to reduce sediment movement into streams. Buffer zones also provide habitats and corridors for wildlife.

The four main types of disturbance that can affect water quality in forested areas are roading (road and track construction, maintenance and use), fire, wood harvesting, and recreation. The most common impact associated with forest management activities is the generation and movement of sediment into drainage lines and water bodies. However, a number of other factors can also reduce water quality. These include pollution from application of fertilisers and herbicides, elevated water temperature where streamside vegetation is cleared, and an increase in biological oxygen demand (the oxygen required for breakdown of organic matter by microorganisms).

Planned and unplanned fires have the potential to affect water quality through increased erosion risk coupled with more intense run-off after rain, which increases flows of sediment, nutrients and other determinants of water quality, such as trace elements. On the other hand, reforestation of land not carrying trees can reduce the adverse impacts of erosion, dryland salinity and waterlogging, by stabilising soils, lowering groundwater levels and decreasing the volume of saline groundwater entering streams or drainage lines.

Planning that aims to reduce the impact of recreation infrastructure and activities (such as roading and traffic) on water quality in reserves is implemented under regulations and under various pieces of state and territory legislation. Although recreation activities are often permitted in reserved forests, a relatively small proportion of the total area is used for access and other visitor infrastructure. Hence, most of the area of nature conservation reserves is not subject to such disturbance activities that might affect soil and water values. Bushfire is the major threat to water quality in reserved forests.

Instruments that address the risks to water quality

Legally binding instruments (such as Acts and licences) and non-legally binding regulatory instruments (such as codes of practice, guidelines and forest management plans) that include measures to protect water quality in catchments where forest management activities are undertaken are in place in all jurisdictions. Key mitigation measures include providing adequate and appropriate drainage for roads, trails and tracks, and protecting streamsides and drainage lines with vegetation buffers or filter strips that minimise soil movement into streams. However, the degree to which measures are prescribed in detail varies across jurisdictions.

The extent to which a regulatory framework requires the maintenance of water quality is rated according to the five categories used in previous SOFRs. These categories are detailed in Table 4.15, and range from Category 1 (for regulatory instruments that take into account many specified types of risk to water quality) to Category 5 (for instruments that do not mention the need to address risks to water quality). The extent to which the risks to water quality are addressed by a state or territory's legally binding and non-legally binding instruments is assessed against these categories in Table 4.16.

The data in Table 4.16 show that there are regulatory instruments in place to protect water quality in all jurisdictions and for all tenures for which this was reported. Most of these instruments rate highly for the number of factors that must be taken into account. This reflects water quality being a major concern and focus of legislative and regulatory instruments. The ratings shown for South Australia have been refined since those reported in SOFR 2013 based on further assessment of the regulatory instruments. Ratings have not changed or were not reported in SOFR 2013 for other jurisdictions.

The Australian Capital Territory has non-legally binding instruments for its public plantation estate (wood harvesting from native forests is not allowed in the Australian Capital Territory). These instruments seek to minimise the risk to water quality by considering streams, drainage lines, water bodies and slope, and by specifying appropriate management practices and streamside buffers. Plantation forestry in the Australian Capital Territory is based on A*CT Code of Forest Practice 2005* (Environment ACT 2005), which focuses

Box Creek falls, Kanangra Boyd Wilderness, NSW.

Table 4.15: Categories of the extent to which the regulatory framework requires the maintenance of water quality

Category	Category description
1	The regulatory instruments require the following components to be taken into account in addressing the risk to water quality from disturbance activities: • stream and drainage lines (e.g. including exclusion zones) • road drainage and stream crossings (e.g. cross-draining of log extraction tracks) • slope • sensitive aquatic habitat.
2	The instruments address most of the components listed in category 1, and those not addressed are associated with low risks to quality for the particular disturbance activity and geographic setting.
3	The instruments address most of the components listed in category 1 but do not specify all aspects or are limited in their application.
4	The instruments mention the need to address risks to water quality when conducting disturbance activities but do not specify the components listed in category 1.
5	The instruments do not mention the need to address risks to water quality.

Source: SOFR 2008.

Table 4.16: Assessed extent to which legally and non-legally binding regulatory instruments address the risk to water quality from forest operations, road and trail works, fire management and recreation

Instruments	Tenure	ACT	NSW	NT	QLD	SA	Tas.	Vic.	WA
Legally binding	Multiple-use public forests	3*	1	n.r.	2	4	1	1	4
	Public nature conservation reserves	n.r.	1	n.r.	n.r.	4	1–2	1	4
	Leasehold land	3*	n.r.	n.r.	2	4	n.r.	n.r.	n.r.
Non-legally binding	Multiple-use public forests	1	1	n.r.	2	1,4[a]	1	2	1,3[b]
	Public nature conservation reserves	1	1	n.r.	n.r.	n.a.	1–2	2	4
	Leasehold land	1	n.r.	n.r.	n.r.	1,4[a]	n.r.	n.r.	n.r.

n.r., not reported; n.a., not applicable

[a] Rating 1 for plantation operations; 4 for other activities.

[b] Rating 1 for native forest operations; 3 for plantation activities.

*, assessed by ABARES.

Note: The extent to which instruments address the risk to water quality varies between 1 (highest rating) and 5 (lowest rating): see Table 4.15. Each rating is an assessment by the relevant jurisdiction except where indicated.

Source: Data for Tas. from FPA (2017a). Data for NSW, Vic. and WA are from SOFR 2013 except that NSW multiple-use public forest data are from Forestry Corporation of NSW. ACT data from ACT Environment, Planning & Sustainable Development Directorate.

This table, together with other data for Indicator 4.1e, is available in Microsoft Excel via www.doi.org/10.25814/5bda9272d76d7

on protecting water quality during plantation activities. Minimum widths for riparian management zones are prescribed, and restrictions are in place for wet weather, and machinery use in drainage lines or depressions, steep slopes and erodible soils. A review of the code concluded that it provides a comprehensive approach to protecting water quality in the Australian Capital Territory (Smethurst et al. 2012). The *ACT Strategic Bushfire Management Plan 2014–2019*[212] (ESA 2014) considers impacts of high-intensity unplanned landscape-scale fires and suppression activities on the water quality of water catchments. Under the *Nature Conservation Act 2014*, management plans are prepared in the Australian Capital Territory for nature conservation reserves; these plans address the risk to water quality from disturbance activities.

New South Wales has legally binding instruments that address risks to water quality for operations in both the native forest and plantation estates. In the New South Wales public native forest estate, Integrated Forestry Operations Approvals contain requirements for assessing and managing risks to soil erosion and water pollution. The approvals contain the terms of a licence under the *Protection of the Environment Operations Act 1997* (NSW) (the 'environment protection licence'). The purpose of the environment protection licence is to control the carrying out of forest operations, including harvesting, thinning and ancillary road construction, for the purpose of regulating water pollution resulting from any such operation.

For the private native forest estate in New South Wales, the *Private Native Forestry Code of Practice 2013* contains provisions for protecting catchment water values. Mitigation measures include establishing riparian exclusion and buffer zones, snig tracks and extraction tracks, appropriate drainage systems and stream crossings, and complying with wet-weather limitations for snigging, log landing and portable mill operations.

Softwood and hardwood plantations in New South Wales are authorised under the *Plantation and Reafforestation (Code) Regulation 2001*, which prescribes standards and regulations relating to the protection of soil and water. Prescriptions

[212] esa.act.gov.au/wp-content/uploads/The-ACT-Strategic-Bushfire-Management-Plan.pdf

cover buffer zones, slope limits, wet weather provisions, and road, track and stream crossing and drainage location, design and construction, maintenance and management during operations.

The *Bush Fire Environmental Assessment Code for New South Wales 2006*[213] provides standards to prevent soil erosion and instability, and standards for the protection of riparian buffers, for bushfire hazard reduction works.

In the Northern Territory, the *Codes of Practice for Forestry Plantations 2004* (DRPI 2004) specifies goals related to the protection of water quality. This code is being reviewed. Management plans for conservation reserves in the Northern Territory also include provisions to protect water values. The Northern Territory also contains a number of stream-gauging stations that collect data on water quality.

In Queensland, the *Forestry Act 1959* requires State forests to be used and managed in a manner to protect water of sufficient quality; the *Environmental Protection Act 1994* and the *Water Act 2000* are the main pieces of legislation under which waters are protected while supporting ecologically sustainable development, but they make no special reference to forestry. Risks to water quality from wood production are managed largely through codes of practice. In 2013, the Queensland Government introduced self-assessable vegetation clearing codes (renamed in 2017 as 'accepted development vegetation clearing codes') in accordance with the *Vegetation Management Act 1999*. For freehold land, *Managing a native forest practice – A self-assessable vegetation clearing code 2014*[214] (DNRM 2014) requires harvesting or removal of vegetation to be carried out in a way that maintains water quality values. The code specifies buffer and filter zone requirements for wetlands and different stream orders.

The Code of Practice for Native Forest Timber Production on the Queensland Parks and Wildlife Service (QPWS) Forest Estate 2014[215] (DNPRSR 2014) is the other legally binding code protecting water quality in Queensland. It prescribes operational standards for timber harvesting, so as to achieve a high level of protection of environmental values, including water quality. Water quality risks from wood production plantations on private land are managed by requirements of the *Timber Plantation Operations Code of Practice for Queensland 2015*[216] (Timber Queensland 2015). Water quality values are maintained in plantations by minimising disturbance to waterways, planning and designing fill disposal areas and embankments, and restricting heavy vehicle traffic during persistent wet or dry weather. With only minor exceptions, all native forest wood production managed by Queensland is certified to the Australian Standard for Sustainable Forest Management[217], which requires management of risks to water quality.

South Australia has legally and non-legally binding instruments for its plantation estate. Non-legally binding 'Industry Best Practice' described in the *Guidelines for Plantation Forestry in South Australia 2009*[218] seeks to minimise the risk to water quality by considering streams, drainage lines, water bodies and slope, and by specifying appropriate management practices and streamside buffers. Following a fire, consideration of water quality protection is necessary in regards to subsequent rain events. *The Environment Protection (Water Quality) Policy 2015* under the *Environment Protection Act 1993*, provides the structure for legally binding regulation and management of water quality in South Australian inland surface waters, marine waters and ground waters. The *Forestry Regulations 2013* made under the *Forestry Act 1950* place controls on activities in reserves to protect water values.

In Tasmania, the risk to water quality is assessed for forest management activities under the *Forest Practices Act 1985*, irrespective of the land tenure or forest type. The *Forest Practices Code 2015*[219] (FPA 2015b) provides guidelines and standards to conduct forest practices for the protection of all watercourses, by minimising disturbance to watercourse channels and riparian (streamside) zones, and by reducing soil disturbance in and near watercourses. The code also meets statutory objectives for water management and water quality standards for human use, by minimising the risk of sedimentation and pollution from forest management activities. The code allows harvesting of plantations that are in streamside reserves and that are within 10 metres of Class 4 watercourses on low to moderate-high erodibility class soils, but does not permit harvesting within 10 metres of a Class 1, 2 or 3 watercourse in plantations established after 1 January 2001. There are supporting manuals such as the *Guidelines for the Protection of Class 4 Streams* (FPA 2011a)[220].

In Victoria, the *Victorian Waterway Management Strategy 2013*[221] (DEPI 2013) sets regional planning arrangements for water quality management and objectives for water quality monitoring in relation to forestry, catchment development, recreational activities, and extreme events such as bushfire and flood.

The *Code of Practice for Timber Production 2014*[222] (DEPI 2014b) applies to all timber production on state forests, private native forests and plantations in Victoria. It outlines specific requirements to maintain or improve water quality and river health by protecting waterways and aquatic and riparian habitat from disturbance, and to prevent soil sediments and other pollutants from entering waterways. Mitigation measures outlined in the code include the establishment of buffer and filter strips, the installation

213 www.rfs.nsw.gov.au/__data/assets/pdf_file/0014/24332/Bush-Fire-Environmental-Assessment-Code.pdf

214 publications.qld.gov.au/dataset/self-assessable-vegetation-clearing-codes/resource/a73f5b44-008c-4f92-8644-f92e6caf6592

215 www.npsr.qld.gov.au/managing/pdf/timber-production-qpws-estate.pdf

216 www.timberqueensland.com.au/Docs/Growing-Processing/Timber-Plantation-Operations-Code-of-Practice-Version-1.pdf

217 www.responsiblewood.org.au/

218 www.pir.sa.gov.au/__data/assets/pdf_file/0011/254765/guidelines_for_plantation_forestry_in_sa_web.pdf

219 www.fpa.tas.gov.au/fpa_services/planning_assistance/forest_practices_code

220 www.fpa.tas.gov.au/__data/assets/pdf_file/0014/110246/Guidelines_for_the_protection_of_Class_4_streams.pdf

221 www.water.vic.gov.au/__data/assets/pdf_file/0019/52543/VWMS-Summary_FINAL_WEB-ready.pdf

222 www.forestsandreserves.vic.gov.au/__data/assets/pdf_file/0016/29311/Code-of-Practice-for-Timber-Production-2014.pdf

of appropriate drainage systems and stream crossings, restrictions on disturbances on steep slopes, the use of silt traps alongside roads, and road closures in wet weather. The *Code of Practice for Bushfire Management on Public Land 2012*[223] (DSE 2012) addresses the potential impacts of fire on water quality, and prescribes measures that minimize the impact of bushfire management activities on the physical, chemical and biological qualities of streams and wetlands.

In Western Australia, the *Forest Management Plan 2014–2023* (CCWA 2013) covers all the main wood production areas in the state's south-west, and emphasises the protection of water values. The plan includes activities to manage the risk of stream salinity as a result of rising groundwater tables, and to manage the risk of surface water turbidity of as a result of erosion or contamination with bacteria, hydrocarbons or pesticides. The *Guidelines for Protection of the Values of Informal Reserves and Fauna Habitat Zones*[224] (DEC 2009a) exclude timber harvesting from informal reserves along streams and rivers to protect water quality. The *Code of Practice for Fire Management 2008* (DEC 2008)[225] guides land managers to balance the impacts of fire management actions on water quality. Risks to water quality through erosion, waterlogging, sedimentation and contamination are managed according to the *Soil and Water Conservation Guidelines 2009* (DEC 2009c). Design, construction and maintenance of unsealed roads to minimise sediments are carried out according to the *Unsealed Roads Manual* of the Australian Road Research Board[226]. Use of certain products, practices or activities is limited or controlled in 'Reservoir Protection Zones'. Drinking water sources are protected by restricting the type of recreational activities allowed, and by controlling pesticide use in these areas.

Assessment of the risk to water quality

Water quality is monitored at many sites across the states and territories to determine whether water for different uses, including drinking water, meets the required standards, but not all these sites are located in forests. It is also not always possible to identify the causes of changes in water quality at a monitoring point, because of the need to consider all activities, land-uses and vegetation types (forest and non-forest) in the catchment above that point, and because it is difficult to measure the many factors that determine the spatial and temporal impacts of forest activities. Assessment of the risk of forest management activities to water quality is generally based on field monitoring of water at a limited number of locations, and comparing water quality parameters against recommended thresholds set out in various guidelines and standards.

The extent to which risks to water quality are assessed in planning processes is rated according to the four categories used in previous SOFRs. These categories are detailed in Table 4.17, and range from Category 1 (for a risk assessment system that takes account of many specific types of risk to water quality) to Category 4 (for a risk assessment system that is ad hoc or does not take into account any of the above risks to water quality).

Table 4.18 shows the proportion of disturbance activities planned in multiple-use public forest in 2011–16, assessed for risks to water quality against these categories, by jurisdiction. In the Australian Capital Territory, New South Wales, Queensland, South Australia, Tasmania, Victoria and Western Australia, assessments of the potential risks to water quality are conducted for forest activities and roading operations in multiple-use public native forests and plantations. However, the assessments have varying levels of robustness. In the states and territories for which data were available, almost all the proposed activities were assessed for risks to water quality.

Table 4.17: Categories of the extent to which risks to water quality are assessed in planning processes

Category	Category description
1	The water quality risk assessment system comprehensively takes account of all the following factors: • stream and drainage lines (e.g. including exclusion zones) • road drainage and stream crossings (e.g. cross-draining of log extraction tracks) • slope • sensitive aquatic habitat.
2	The water quality risk assessment system takes into account most of the components listed in category 1, and those not addressed are associated with low risks to water quality for the particular disturbance activity and geographic setting.
3	The water quality risk assessment system takes into account some of the factors listed in category 1 or only partially accounts for these factors.
4	The water quality risk assessment system is ad hoc and/or does not take into account any of the factors listed in category 1.

Source: SOFR 2008.

[223] www.ffm.vic.gov.au/__data/assets/pdf_file/0006/21300/Code-of-Practice-for-Bushfire-Management-on-Public-Land.pdf

[224] library.dbca.wa.gov.au/static/FullTextFiles/069674.pdf

[225] www.dpaw.wa.gov.au/images/documents/fire/fms-code-of-practice.pdf

[226] www.arrb.com.au/manual-guides

Table 4.18: Proportion of disturbance activities in multiple-use public forest assessed for risk to water quality, and assessed category

Disturbance activity	Metric	ACT	NSW	NT	Qld	SA	Tas.	Vic.	WA
Native forest harvesting and silviculture	Assessed for risk to water quality (%)	n.a.	100	n.a.	100	n.a.	100	n.r.	100
	Assessed category[a]	n.a.	1	n.a.	2	n.a.	1	1	2
Plantation operations	Assessed for risk to water quality (%)	100	100	n.a.	n.r.	100	100	n.r.	100
	Assessed category[a]	1	1	n.a.	n.r.	1	1	1	3
Road construction and maintenance	Assessed for risk to water quality (%)	100	100	n.a.	n.r.	100	100	n.r.	100
	Assessed category[a]	2	2	n.a.	n.r.	2	1 (MUF) 2 (NCR, OCL, Pv[b])	1	2
Fire management	Assessed for risk to water quality (%)	100	100	n.a.	n.r.	100	100	n.r.	n.r.
	Assessed category[a]	2	2	n.a.	n.r.	2	1 (MUF) 2 (NCR, OCL, Pv[b])	1	n.r.

n.r., not reported; n.a., not applicable. MUF, multiple-use public forest; NCR, nature conservation reserve; OCL, other Crown lands; Pv, private.

[a] The extent to which risks to water quality are assessed in planning processes varies between 1 (highest rating) and 4 (lowest rating): see Table 4.17. Areas harvested are reported in Indicator 2.1a and areas burned in Indicator 3.1b.

[b] Additional information for other tenures provided by Tasmanian agencies.

Source: Data for ACT, Queensland, Tasmania and Western Australia are from SOFR 2013. Data for NSW are from Forestry Corporation of NSW and the Department of Primary Industries Plantation Assessment Unit. NT has no multiple-use public forests.

This table, together with other data for Indicator 4.1e, is available in Microsoft Excel via www.doi.org/10.25814/5bda9272d76d7

The data in Table 4.18 show that there are regulatory instruments in place to protect water quality in all jurisdictions and for all activities for which this was reported. These instruments rate highly for the number of factors that must be taken into account. This reflects water quality being a major concern and focus of legislative and regulatory instruments.

Water quality knowledge base

The knowledge base relating to forest management activities and water quality is reasonably strong in all jurisdictions, and is particularly strong in regards to soil erosion and related mitigation measures. Research continues on suspended sediment export, and implications of bushfires for the quality of water available to downstream users.

The Forestry Corporation of New South Wales monitors water quality in native forests and plantations, across various intensities of harvesting and road activities, and across soil types, to investigate the potential impacts of forest activities on stream sediment and downstream water quality. For example, a replicated catchment experiment in native eucalypt forest in Kangaroo River State Forest, near Coffs Harbour, showed that selective harvesting using best management practices did not affect suspended sediment yields in two of three treated catchments; in the third catchment, an increase in event sediment loads and concentration, at the time of harvesting, subsided within 12 months (Webb et al. 2012b; see also Case study 4.1). Walsh (2017) assessed the impact of harvesting in small head-water (zero-order) catchments and in 10-metre buffer strips on water turbidity and sediments in the Brooman State Forest, near Batemans Bay. Harvesting increased runoff and sediment levels but not mean turbidity or sediment concentration, and sediment levels dissipated over 18 months where there was no harvesting in the buffers. Webb and Hanson (2013), working in coastal catchments on the mid-north coast of NSW, showed that preventing or reducing road-to-stream drainage connectivity is essential for reducing the impacts of roads on water quality.

In Victoria, knowledge of the risk posed by post-fire debris flows and other hydro-geomorphic changes in different locations in the landscape has improved following the 2009 bushfires in Victoria (Jones et al. 2014; Nyman et al. 2015; Langhans et al. 2016). Post-fire debris flows are major sources of fine suspended sediment, and a risk to water quality in forest catchments, as sediment flow rates can be 2–3 orders of magnitude higher than annual background erosion rates (Cawson et al. 2012; McInnes-Clarke et al. 2014; Nyman et al. 2011, 2015; Sheridan et al. 2015). Susceptibility to debris flow varied with slope, burn severity and aridity (Nyman et al. 2015). The effects of prescribed burning on surface runoff, erosion and water quality, however, were shown to be minimal and to last only for a short period (3 months to 1 year) (Cawson et al. 2012), due to the general low fire intensity and burn patchiness. The most significant runoff, erosion and water quality impacts of prescribed burns occurred when these were followed by an intense storm. Sheridan et al. (2015) showed that higher aridity (a function of long-term mean precipitation and net radiation) is associated with lower post-fire infiltration capacities, increasing the chance of surface runoff and debris flows.

In South Australia, there is reasonable knowledge on the impacts of forest management activities on water quality. The Environment Protection Authority (EPA) monitors the water quality of waterways, with the data used to produce annual Aquatic Ecosystem Condition Reports.

Tim Clancy

One of 17 monthly sampling sites established in 1998 for long-term monitoring of water quality at the Warra Long-term Ecological Research site, southern Tasmania.

Western Australia has long-term datasets on the response of streamflow, stream salinity and groundwater to wood harvesting in the south-west region. These datasets underpin silvicultural specifications, stream zone dimensions, and rehabilitation practices. The risk to water quality due to salinity has reduced due to significant declines in annual rainfall and dropping groundwater levels. In the *Forest Management Plan 2014–2023* (CCWA 2013), the Swan and South West regions and parts of the Warren Region[227] have therefore been reclassified as 'low salt sensitivity', with phased harvesting now only required in those parts of the Warren Region classified as 'moderate salt sensitivity' (DPaW 2016a).

Tasmania has well-developed knowledge on water quality in multiple-use public forests and some private forest areas. The Department of Primary Industries, Parks, Water and Environment manages the Water Quality Database, with water quality routinely monitored at 86 stream gauging sites, with spot sampling of turbidity, dissolved oxygen, pH, electrical conductivity and water temperature (FPA 2017a). Streams within catchments with a history of forest management operations showed no significant impacts on stream health, and possessed similar macroinvertebrate communities to those without forest management operations. There were no records of triazine contamination of streams from forest plantations in the reporting period (FPA 2017a). In 2015, a review of the Giant Freshwater Lobster Recovery Plan noted sedimentation arising from clearing in headwater streams as a key threat to juvenile lobsters, and recommended research on optimal headwater streamside buffers to reduce downstream sediment flows (DoEE 2015). Magierowski et al. (2012) showed that freshwater macroinvertebrate biodiversity was most significantly affected by grazing land use in catchments and by riparian vegetation condition, with minimal impacts from upstream production forest management. Case study 4.3 describes research into this issue.

[227] Administrative regions within the South-West Forest Region covered by the FMP 2014–2023.

Table 4.19: Compliance with environmental protection requirements on Crown and private land, NSW, 2011–12 to 2015–16

	2011–12	2012–13	2013–14	2014–15	2015–16
Number of EPA audits and investigations undertaken on Crown land	39	94	66	55	37
Number of non-compliances with EPL detected on Crown land	414	127	15	10	29
Number of EPA audits and inspections undertaken on private land	n.r.	258	148	32	n.a.
Number of corrective action requests issues for private land	n.r.	59	37	5	n.a.

n.r., not reported; n.a., not applicable

Notes: EPL, environment protection licences. Non-compliances include administrative errors, as well as matters relating to soil erosion and water quality. Corrective action requests include 'show cause' notices, 'clean-up' notices, and official cautions.

Source: Annual reports, Implementation of NSW Forest Agreements and Integrated Forestry Operations Approvals, EPA NSW[228].

This table, together with other data for Indicator 4.1e, is available in Microsoft Excel via www.doi.org/10.25814/5bda9272d76d7

Compliance with water quality measures

Assessing compliance with requirements for the protection of water quality is related to the process of assessing compliance with measures to prevent soil erosion (see Indicator 4.1b). All states and territories audit compliance with requirements for the protection of water quality.

In New South Wales, the Environment Protection Authority (EPA) has developed risk-based compliance strategies to guide regulation of forest management operations in native forests on both private and public lands. The EPA audits and assesses compliance against the compliance priorities, which for example in 2015–16 were protection of water quality and in-stream habitat degradation resulting from inadequate road and snig track crossing location, design, construction, operation and maintenance, and protection of vegetation adjoining streams and drainage features to maintain water quality and riparian habitat (EPA 2016)[229]. The results of audits and investigations of compliance with environmental protection requirements on Crown and private land in New South Wales are shown in Table 4.19. The data show performance improvements across the reporting period.

In Queensland, the Australian Standard for Sustainable Forest Management certification audits are conducted for native forest harvesting authorised under the *Forestry Act 1959* as a component of Department of Agriculture and Fisheries (DAF) forest management certification. DAF and the Department of National Parks, Sport and Recreation also audit native forest harvesting operations. No significant non-compliance or breach for native forest activities authorised under the *Forestry Act 1959* was reported during the 2011–16 reporting period.

In South Australia, there were no reported completed prosecutions or civil penalties under the *Environment Protection Act* relating to forest management during the 2011–16 reporting period[230]. The *Natural Resources Management Act 2004* and the *Environment Protection (Water Quality) Policy 2015* also contain penalty provisions for regulatory breaches. The majority of forest plantation managers in South Australia have independently audited systems for sustainable forest and land management. Short-term and long-term water monitoring by ForestrySA in the Mount Lofty Ranges provided no significant detections of any herbicide used by ForestrySA for its forest management operations; herbicides not used by ForestrySA were found in some samples at low levels and are believed to have originated from upstream sites not managed by ForestrySA (ForestrySA/PIRSA 2015).

In Tasmania, forest operations managed by Forestry Tasmania[231] are regulated by the Forest Practices Authority, with independent annual audits. During 2015–16, the Forest Practices Authority audit examined 19 Forest Practices Plans developed by Forestry Tasmania; compliance was rated at the highest level obtainable on all 11 criteria examined. No breaches were recorded related to protecting water values (Forestry Tasmania 2016a). Furthermore, in 2014–15 none of the water samples taken from streams after chemical application within production forests contained detectable chemicals (Forestry Tasmania 2016b), consistent with adherence to guidelines and Codes of Practice requirements during aerial and ground-based chemical applications.

A case study from northern Tasmania showed that harvesting a 20-year-old shining gum (*Eucalyptus nitens*) pulpwood plantation from a streamside management zone using management practices from the Code of Forest Practice did not affect water quality or stream turbidity (Neary et al. 2010).

In Victoria, river health is monitored at eight-year intervals through the Index of Stream Condition (ISC), which measures 1,200 river reaches representing 29,000 kilometres of major rivers and tributaries. ISC data from 2013 showed that 23% of the total river length in Victoria was in good to excellent condition, but 45% of the river length within forested catchments was in good to excellent condition. River condition was better in eastern Victoria than in western Victoria, and better in public forests than private forests, with results corresponding closely with the extent of forest cover in each catchment (DEPI 2014a[232]).

[228] www.epa.nsw.gov.au/your-environment/native-forestry/native-forestry-nsw-overview/regulating-native-forestry/native-forestry-compliance-update

[229] www.epa.nsw.gov.au/your-environment/native-forestry/integrated-forestry-operations-approvals/annual-reports

[230] www.epa.sa.gov.au/data_and_publications/completed_prosecutions_and_civil_penalties

[231] From July 2017, Sustainable Timbers Tasmania.

[232] www.forestsandreserves.vic.gov.au/__data/assets/pdf_file/0019/52705/VIC_SFR2013_lowres.pdf

Case study 4.3: Effect of upstream forest management on stream ecosystem condition in middle catchment reaches in Tasmania

Davies et al. (2016) studied the impact of upstream forestry operations on downstream mid-catchment stream reaches in Tasmania. Downstream study sites were situated in fourth-order stream reaches[234] with no adjacent forestry activity, and changes in stream ecosystem condition were taken to represent the accumulated effect of management activity in the upstream catchment. Harvesting operations occurred from before 1987 to 2007, but mostly occurred before 1991; sites harvested before 1987 were harvested before formal adoption of the Tasmanian Forest Practices Code under the *Tasmanian Forest Practices Act (1985)*. Plantations were either hardwood (generally shining gum, *Eucalyptus nitens*) or softwood (generally radiata pine, *Pinus radiata*), established on former native forest sites.

Impacts of upper-catchment forestry operations were detected in mid-catchment river reaches up to 10 km downstream (Table 4.20). Macroinvertebrate community composition, measured as the proportion of three aquatic insect families, was affected by unsealed roads and/or (in four out of seven catchments) by clearfell, burn and sow harvesting operations in native forests. Variation in the area proportion of unsealed roads explained 75% of the variance in the responses of these aquatic insect taxa. Based on a combination of field evidence and independent experimental evidence, the mechanism was deduced to involve deposition of fine sediments. Populations of juvenile giant freshwater crayfish (*Astacopsis gouldi*) declined marginally with an increasing proportion of upstream land subject to clearfell operations.

Plantation forestry operations had less effect on sediment levels and no impact on downstream macroinvertebrates. This may be because catchments containing plantations had a smaller area of unsealed roads, and were generally on less erodible (basaltic) soils compared to the more erodible soils in catchments containing native forest harvested by clearfell techniques.

The Forest Practices Code protects streams of order 2–4 by requiring riparian buffer zones of at least 20 metres in width. Additionally, operational guidelines adopted since 2004 include buffer zones around headwater streams where there is significant erosion risk. Other management prescriptions to reduce impacts include increased engineering and maintenance standards for unsealed roads to reduce sediment movement into streams, including for roads outside the specific areas covered by forest practices plans; measures to increase interception of sediment following rainfall and runoff after broad-scale burning; and area limits for clearfell operations. These could be provided in a catchment-level or estate-level approach to forest management, using long-term forest practices plans that vary with geological and soil context and that complement established coupe-scale prescriptions.

Adapted from Davies et al. (2016)

Table 4.20: Response of stream conditions parameters to forest harvesting, roading and plantation area

	Response of parameter to forestry operations		
Stream condition parameter	**Response to proportion of catchment area subject to clearfell operations**	**Response to proportion of area under unsealed roads in catchments with clearfell operations**	**Response to proportion of area under plantation**
Proportion of aquatic EPT insect taxa[a]	In four of seven catchments, declines as area proportion of CBS increases above 40%	Declines when area of unsealed roads is above 2%	Not affected
Benthic algal cover or biomass	Not affected	No data	Not affected
Organic detritus	Increases as area proportion of CBS increases above 40%	No data	Not affected
Silt	Increases as area proportion of CBS increases above 40%	No data	Increases when area proportion of plantations is above 80%
Sand	Increases as area proportion of CBS increases above 40%	No data	Not affected
Fine sediment	Increases as area proportion of CBS increases	Increases when area of unsealed roads above 2%	Not affected
Giant freshwater crayfish (*Astacopsis gouldi*)	Declines marginally as increasing area proportion of clearfell increases	No data	No data
Stream channel and bank condition[b]	Not affected	No data	Not affected

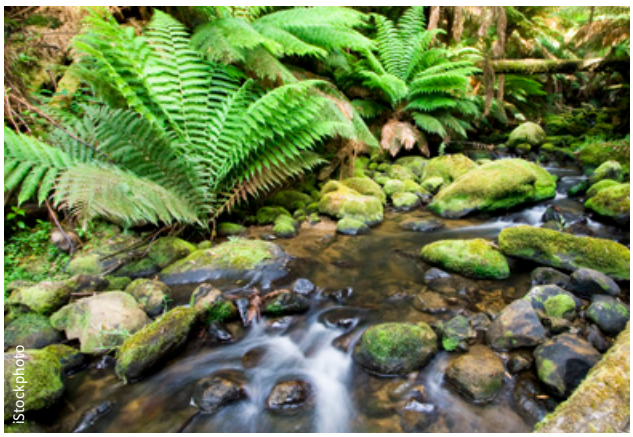
Note: 'CBS' – clearfell, burn and sow.

[a] EPT taxa: the aquatic insect orders Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies), which have a high species diversity in Tasmania and are sensitive to anthropogenic impacts.

[b] Dominant bed material type, bank shape, area of bank erosion and quantity of large wood.

[234] First-order streams are headwater streams in Tasmania.

In Western Australia, the Department of Parks and Wildlife[233] oversees approvals, monitoring and compliance of disturbance activities in state forests and timber reserves, with audits of forest management activities against the requirements of the *Forest Management Plan 2014–2023* (CCWA 2013). In 2015, the then Department of Parks and Wildlife issued 13 notification reports and 3 works improvement notices related to soil and water (DPaW 2016c). Informal river and stream reserve zones for water protection are of width 60–400 metres depending on stream order; assessment of these zones in harvesting coupes showed 99.9% compliance, with a single minor incident involving machine activity across a reserve boundary.



Great Otway National Park, Victoria.

[233] From July 2017, the Department of Biodiversity, Conservation and Attractions.

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