# The Upper Fortescue region

CSIRO has completed, for the Government of Western Australia and industry partners, an overview of the current and future climate and water resources of the Pilbara to aid water planning and management. These resources included regional surface water, groundwater and environmental water, and allowed local studies to be placed into a regional context. The Pilbara Water Resource Assessment covers an area of 288,479 km$^2$, which is about 11% of the state of Western Australia. This is one of the world's most important resource regions for high-grade iron ore deposits and offshore gas reserves. Irrigated agriculture may also expand to augment the area's long-term grazing industries.

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The Upper Fortescue region has become a major iron ore–producing area since mining commenced in the 1960s, but it supports a population of little more than 10,000 people. It is located in one of the hottest parts of Australia and has highly variable rainfall. Pastoral stations owned by both mining companies and private graziers are the main land uses, along with undeveloped vacant crown land.

The main physiographic feature is the Hamersley Range. Mount Meharry, the highest peak in Western Australia, with an elevation of 1249 m, is located in the southern part of Karijini National Park just outside the region.

The Hamersley Range has an orographic effect, with some peaks having an annual rainfall almost twice that of adjacent flatter areas. However, the area is semi-arid, with maximum temperatures in summer often exceeding 40 °C. The annual rainfall deficit (rainfall – Class A pan evaporation) ranges from about 2400 mm in the Hamersley Range to more than 3100 mm in low-lying areas. Potential evaporation exceeds rainfall by 7 to 13 times, depending largely on elevation.

Rainfall is summer dominant, and is mainly associated with thunderstorms and occasional tropical cyclones and tropical depressions, which result in runoff once infiltration thresholds are exceeded.

The physiography is dominated by its underlying geology, which results in many fractured rock outcrops. Archean granite–greenstone rocks occur in the south, associated with the Sylvania Inlier. Most of the region is part of the Archean–Proterozoic Hamersley sedimentary basin, which comprises the Fortescue Group (mainly associated with the Chichester Range), the Hamersley Group (associated with the Hamersley Range), and the Pinjian and Manganese groups (associated with the Upper Fortescue Valley and East Upper Fortescue). The Wittenoom Formation, which contains karstic dolomites, is associated with the Fortescue Valley and underlies some valleys in the Hamersley Range. Erosion and deposition in the Cenozoic formed deep paleochannels, which contain important aquifers and channel iron deposits (CIDs). More recent shallow alluvial deposits coincide with the modern stream network.

Soil profiles in the region are weakly developed because of the hot, arid climate and sparse vegetative cover. Upland soils in particular are skeletal,

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which enhances runoff during high-intensity rainfall events. More developed alkaline, clay-rich and saline soil profiles are associated with the Upper Fortescue Valley and Fortescue Marsh.

## Water resources of the Upper Fortescue region

Groundwater is the main water resource in the region. Ophthalmia Dam on the Upper Fortescue River is used to recharge a downstream paleochannel aquifer. Leakage from streambeds is considered to be the main source of localised recharge, although some diffuse recharge is believed to occur through fractured rock aquifers in major storm events. Therefore, the amount of rainfall required to initiate streamflow and how this may change under a future climate are very important.

There are three main types of aquifers capable of providing water in substantial quantities in the region: (i) alluvial and paleochannel (Cenozoic) aquifers, especially if they contain CIDs; (ii) dolomites of the Wittenoom Formation aquifers, often karstic; and (iii) localised aquifers associated with the zone of iron mineralisation in banded iron formations (BIFs).

The modern alluvial deposits occur along the current stream network. These formations do not contain substantial groundwater resources as they are relatively thin. However, these systems often coincide with older and usually deeper Cenozoic deposits (paleovalleys). In such cases, their presence is significant because of their association with the current stream network and transmission of localised recharge to the underlining aquifers.

Groundwater salinities reflect the degree of flushing in different parts of the region. The lack of surface water (and possibly groundwater) drainage has resulted in hypersaline groundwater under the Fortescue Marsh and adjacent parts of the Chichester Range. Groundwater levels in the region rose significantly in response to the 1995 to 2001 wet period. Since then, they have declined but are not back to pre-1995 levels.

Increasingly large volumes of mine dewater are discharged to the landscape – into riverbeds in the Hamersley Range and often injected into adjacent aquifers in the Chichester Range to prevent mine dewater entering the saline Fortescue Marsh. Some mine dewater is used in mining operations, especially in dust control. Groundwater is used to provide water for the Newman townsite. Pastoral water supplies are often supplied from bores into shallow alluvial material or from fractured rock aquifers.

## Hydrogeological provinces in the Upper Fortescue region

There are five hydrogeological provinces in the Upper Fortescue region (Figure 1): Hamersley Range, Upper Fortescue Valley, Chichester Range, Sylvania Dome and East Upper Fortescue.

The **Hamersley Range** province has the highest elevation and highest rainfall in the region, resulting in a milder climate (25% lower rainfall deficit than surrounding provinces). River valleys within the Hamersley Range contain alluvial aquifers with varying thickness, depending upon the history of landscape erosion or eroded material deposition. They are also crossed by paleochannels, including some with very highly transmissive CIDs, which constitute major iron ore deposits.

Runoff in this province can be generated when daily rainfall exceeds 15 mm; however, average annual runoff is only about 10 mm. Some drainage lines are being increasingly affected by discharge from open-cut iron ore mines, which extend below the watertable. This extends the time that water flows in these creeks. However, annual streamflows are mainly the result of runoff during intense summer rainfalls.

Important aquifers are associated with paleochannels and the dolomite of the Wittenoom Formation.

Under future climate scenarios, mean annual runoff could increase by about 21% under a wet future climate or decrease by about 56% under a dry future climate. Very low runoff years (<10th current percentile) decrease under a wet future climate by about 50% and increase under a dry future climate by about 83%, indicating that recharge to alluvial aquifers and their groundwater-dependent ecosystems (GDEs) could be impacted were these climates to eventuate. Only about

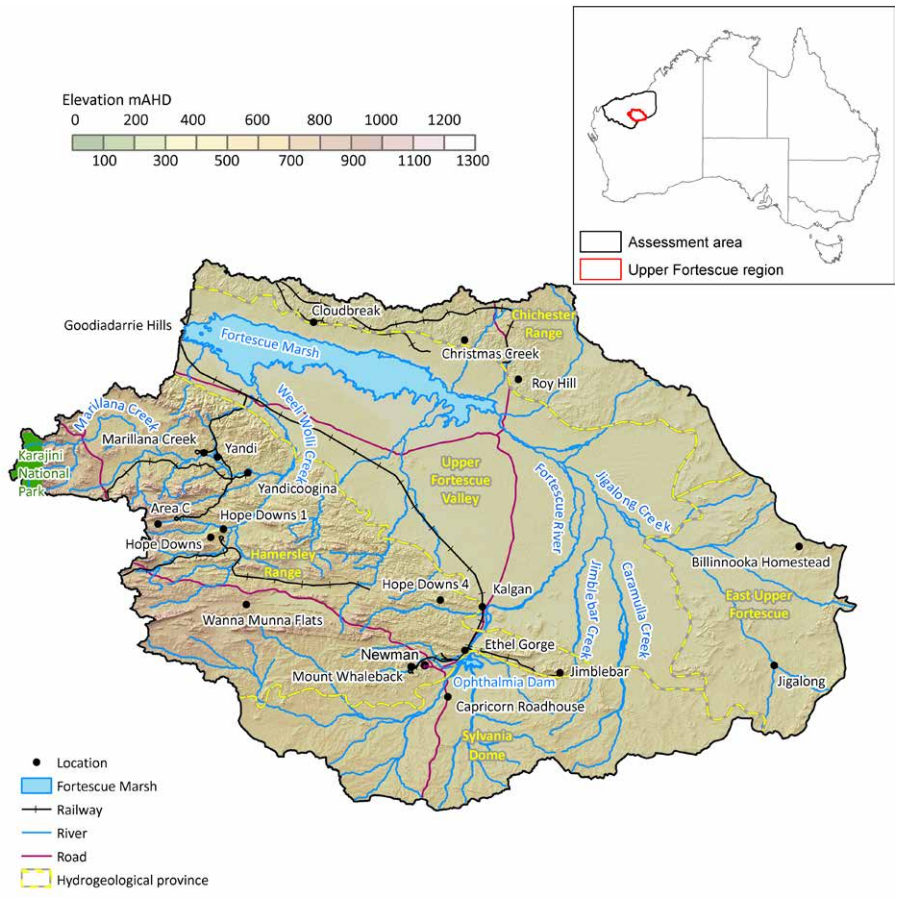


**Figure 1 The Upper Fortescue region's relief, rivers, settlements, national parks and nature reserves, and hydrogeological provinces**

1.5 mm/year becomes recharge over the province as estimated by rainfall–runoff modelling. This could increase by about 10% under a wet future climate and decrease by about 44% under a dry future climate. The latter may have significant impacts on the varied GDEs in the province.

The **Upper Fortescue Valley** province comprises a low-lying and very flat landscape formed between the Hamersley and Chichester ranges, and overlying the dolomite of the Wittenoom Formation. The province encloses the Fortescue Marsh, a terminal drainage, containing hypersaline water in the aquifers below the marsh. It is also periodically inundated with fresh surface water inflows from the Upper Fortescue River and fresh groundwater from both the ranges and valley.

All surrounding provinces are projected to generate large decreases in mean runoff under a dry future climate (–54% to –61%) and less significant increases under a wet future climate (+17% to +21%). Less runoff and fresh groundwater seepage would result in less inundation of the marsh, which is likely to adversely affect dependent flora and fauna. About 1.6 mm/year is estimated to become recharge through streambeds in the Upper Fortescue Valley, using estimates from a rainfall–runoff model. This may increase by about 10% under a wet future climate or reduce by about 45% under a dry future climate.

The **Chichester Range** province has a much lower elevation than the Hamersley Range, and only has a small orographic effect on climate in the north-west. Catchments are small, and alluvial deposits can be clayey, having formed from volcanic and sedimentary bedrock. The potential to recharge these aquifers is therefore limited.

The mineralised Marra Mamba Iron Formation contains abundant water, as evidenced by mining below the watertable in the Cloudbreak, Christmas Creek and, more recently, Roy Hill areas. It is also very transmissive. Groundwater salinities increase towards the centre of the Fortescue Marsh. This province is noted for large-scale reinjection of water from mine sites to avoid disposal of water to the marsh.

The **Sylvania Dome** province contains low granitic hills and surrounding thin, sandy alluvial aquifers, which can be recharged during streamflow. Most groundwater resources within the province are associated with paleovalleys adjacent to the current Upper Fortescue River, which support Ethel Gorge, a major environmental asset in this province.

About 20 mm per event of rainfall is required to initiate runoff, similar to the East Upper Fortescue province, which also has shallow bedrock. Under a wet future climate, mean annual runoff may increase by about 17%, but under a dry future climate the decrease could be about 61%. Recharge estimated using the rainfall–runoff model is estimated to be about 0.9 mm/year. Recharge is projected to remain largely unchanged under a future wet climate but is projected to decrease by 18% under a dry future climate.

The **East Upper Fortescue** province is the most arid province, formed over clay-rich sedimentary rocks and therefore containing few aquifers or alluvial aquifers associated with its streams. Alluvial aquifers are thin and easily filled, so GDEs can be sustained even if they are limited in area. Bedrock is clay-rich and little fractured. No deep paleochannels have been identified, but there has been limited drilling, so they may be present. As a result, groundwater resources are not expected to be extensive in this environment.

About 0.9 mm/year is estimated to become recharge over the whole province. This may remain similar under a wet future climate but decrease by up to 18% under a dry future climate. The future dry climate is drier than the future wet climate, but the low storage in the East Upper Fortescue province may restrict recharge in above-average rainfall years.

## Basis of the assessment

Weather observations were more plentiful and widespread in the 1950s and 1960s, when there were sheep stations throughout the region. More recently, iron ore mining companies have been recording climate data and streamflows at mine sites. However, these latter monitoring data are not yet long term and may not have the longevity of past gauging if they cease when mining moves or ends. Long-term surface water gauging is especially limited in this region.

Groundwater and GDE investigations are very numerous and intensive at only a few locations, as evidenced by reports to regulators. Companies are developing strategic environmental assessments which is resulting in disparate mine site data being brought together. However, non-mineralised areas have only limited data from shallow drilling for stock water.

The Assessment has used the available long-term data and specific studies to draw a regional picture, which hopefully puts the more intensive studies into a broader context. While there are many local groundwater models used by the mining companies, there were no broader-scale models to evaluate the impact of future climate scenarios in the Upper Fortescue region, unlike in the other three regions.

**Cattle using river pool and riparian vegetation**

## Key points

- The Upper Fortescue region has an extreme climate, characterised by extremely hot summers, high potential evaporation and intermittent intense rainfall. Limited information indicates that many soils are skeletal and may be poorly suited for intensive agriculture.
- The main water resources in the Upper Fortescue region are groundwater contained within the dolomites of the Wittenoom Formation, and shallow alluvial and often deeper paleochannel aquifers; some of the latter are associated with CIDs of considerable economic value.
- Future climates are expected to become 1.8 to 2.9 °C hotter by 2050, but it is not clear whether it will be wetter or drier. In general, an ensemble of 18 global climate models (GCMs) suggests that a drier future climate is more probable than a wetter climate. Recent decades have experienced above-average rainfalls. It is unclear how several factors may be contributing, such as (i) increased aerosol concentrations in the atmosphere around South-East Asia, (ii) higher sea surface temperatures in surrounding or remote oceans as a result of climate change, or (iii) natural variability.
- Streamflow is initiated after rainfall exceeds 10 to 16 mm per event. Only 2.0% to 5.5% of annual rainfall (8 to 18 mm) becomes runoff in most years.
- Much of the Upper Fortescue region is underlain by fractured rock formations, which can form local aquifers. Groundwater recharge to these aquifers is mainly associated with rainfall infiltration (diffuse recharge), which has been estimated to vary between 1% and 5% of annual rainfall, mainly associated with rainfall events greater than 20 mm/day, a similar threshold to that required to initiate runoff.
- Leakage from streambeds (localised recharge) is the main mechanism for recharging alluvial and underlying aquifers. The area and duration of riverbed inundation determine the amount of localised recharge.
- Estimated from rainfall–runoff modelling, net recharge in the four hydrogeological provinces for which it could be calculated ranges between 0.9 and 1.6 mm/year. On a volumetric basis, runoff exceeds recharge by between two and eight times. This may result from very large and rapid streamflows in cyclonic events, at which time streambeds may be saturated, which reduces the likelihood of recharge.
- For each 1% change in rainfall, runoff changes by about 3%. Local recharge from streambeds generally decreases by a much lower percentage than the reduction in runoff.
- Runoff may increase by up to 35% in 2050 under a wet future climate but may decrease by up to 61% under a dry future climate, relative to that of the historical baseline period of 1961 to 2012. A major reduction of streamflow into the Fortescue Marsh could have important ecological impacts if it were to eventuate.
- Because of climatic conditions, groundwater resources in the Upper Fortescue region have an important environmental value, supporting multiple terrestrial ecosystems.
- GDEs, including springs and groundwater-dependent terrestrial vegetation, comprise less than 0.5% of the region but have important environmental, social and cultural values. Analysis of satellite remote sensing over a 24-year period (1988 to 2011) indicates that GDEs generally showed limited variability.
- GDEs are ultimately groundwater discharge zones and can be supported by various groundwater systems: those that form aquifers (e.g. karstified dolomites or paleochannels) and those that do not (e.g. shallow alluvial systems).
- Compared with other GDE types, GDEs sustained by regional groundwater discharge are the least sensitive to climate variability. Their characteristics were constant between 1988 and 2011, except where GDEs were affected by groundwater extraction.
- GDEs sustained by groundwater discharge from local aquifers are sensitive to extreme climate variability, such as during 1990–1992, when annual rainfall was less than 200 mm and its low intensity limited recharge.
- The GDEs most sensitive to climate variability are those associated with groundwater systems that do not form aquifers (e.g. break-of-slope).
- The strong interdependence of geology, topography, soil and vegetation associations, hydrology and aquifers has enabled five hydrogeological provinces to be defined to help identify repeating patterns in the water resources of the region.
- There is sufficient low-salinity water in the region for residential use and stock watering. Excess fresh water is discharged to creek lines during mining below the watertable in the Hamersley Range. Groundwater under the Fortescue Marsh is hypersaline except after major flooding. Groundwater in the Chichester Range becomes progressively more saline with proximity to the marsh. Fresh water for mine use is limited in parts of this range.

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