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DEPARTMENT OF
NATURAL RESOURCES, ENVIRONMENT, THE ARTS AND SPORT

# Groundwater
## in the Daly Basin January 2009

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Cover photo: The Daly River, Steven Tickell

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## Summary

The Daly Basin is a geological basin that contains two major aquifers in limestone formations. Groundwater cannot move between the aquifers as they are separated by impervious siltstone formations.

Significant recharge to the aquifers occurs in most years. The groundwater drains to the Daly River and its major tributaries, causing them to flow all year round. These permanent streams support distinctive ecosystems both within the river and along its banks.

The aquifers store and transmit significant volumes of groundwater.  Quantities suitable for irrigation can often be extracted from individual bores. There is a small but increasing agricultural industry. Water allocation plans are currently being developed to ensure that both surface waters and groundwaters are used sustainable. Maintanence of dry season river flows and of the ecosystems that they support are the main guiding principles behind water management in the basin.

## What is the Daly Basin?

Some 400 to 500 million years ago a shallow sea extended over a wide area of the northern and central parts of the Northern Territory and western Queensland (Figure 1). Sands and muds made up mainly from calcium carbonate, accumulated in the sea and over time these hardened to become limestone, siltstone and sandstone.

Mild tectonic forces caused sagging of the crust and the rocks are now preserved in three basin structures. These are referred to as the Daly, Georgina and Wiso Basins. The Daly Basin is the northern-most and is separated from the other two by ridges in the floors of the basins. Rocks that are at ground level around the edge of the Daly Basin are now found at depths of up to 700 metres in its centre. The sagging was not circular as in an idealised basin but elongated in a north west / south east direction, probably controlled by faults.

There are three distinct layers in the Daly Basin. From bottom to top they are the Tindall Limestone, the Jinduckin Formation and the Oolloo Dolostone (Figure 2). Limestone and dolostone are the main rock types in the Tindall and Oolloo but the Jinduckin Formation is made of siltstone, limestone and sandstone (Plate 1). The maximum recorded thickness of the rocks in the basin is 709 m and the maximum recorded thicknesses of the individual formations are: Tindall Limestone 204m, Jinduckin Formation 356m and Oolloo Dolostone 225m respectively.

Changing environmental conditions, such as sea level fluctuations were responsible for different types of sediments being deposited at different times. The Tindall Limestone and Oolloo Dolostone were deposited on a marine shelf ranging from open water to just below the tidal limit. Most of the sediment was sourced locally and consisted of mud and sand composed of calcium carbonate. Some was biological in origin produced as shells or by algae, while some was chemically precipitated directly from the seawater. Land derived sediments such as clay and quartz sand and silt usually form a minor component of the two formations but in the case of the Tindall Limestone they increase towards the northern end of the basin.

Contrasting with the other two formations is the Jinduckin Formation which is dominantly siltstone with minor limestone and sandstone beds. It was deposited in the intertidal zone and was sourced from a mixture of land derived and calcium carbonate sediment.

A distinctive feature of this formation is the local presence of evaporite minerals (salts), notably anhydrite (hydrated calcium sulphate) and halite (sodium chloride). These occur in parts of the basin and are restricted to particular beds in the lower half of the formation. They represent the salts remaining after a body of saline water such as a lagoon has dried up. Their presence affects the quality of groundwater in that formation.

The Daly Basin overlies a variety of older rocks. In the north they comprise granite as well as sedimentary rocks such as greywacke and sandstone. The southern part of the basin is mainly underlain by basalt. The sea floor was only gently undulating when the basin sediments accumulated.

The sea retreated and for about 300 million years the landscape was subjected to erosion and no further sedimentation took place. Then during the Cretaceous period at around 100 million years ago the sea returned and deposits of clay and sand blanketed the area. From then to the present day the area has been dry land and again subject to erosion. Much of the Cretaceous sediment has been eroded away, particularly in the north (Figure 3).

## Groundwater

### Aquifers

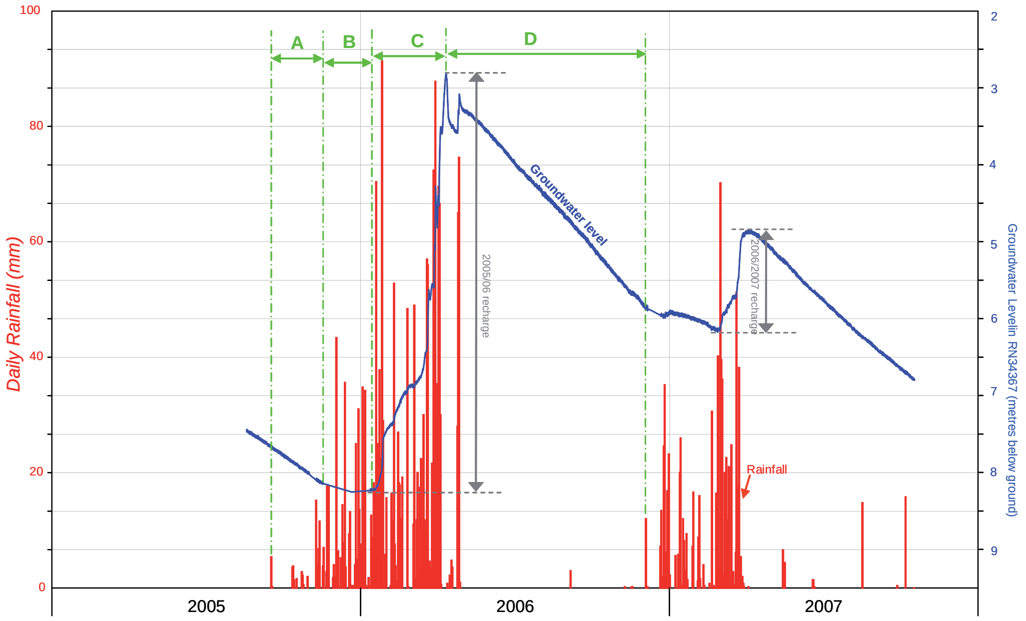
An aquifer is a body of rock or sediment which holds and allows water to move through it, and which is capable of yielding usable quantities of groundwater to boreholes and springs. The Tindall Limestone and the Oolloo Dolostone host widespread productive aquifers. The Jinduckin Formation contains aquifers but they are more localised and less productive than those in the other formations. Layers within the formation act as barriers which prevent groundwater moving between the Tindall and Oolloo aquifers.

Most aquifers in the Daly Basin occur in limestone and dolostone and are formed from networks of interconnected fractures and solution cavities. Fractures are cracks in the rock caused by tectonic forces or from stress relief as overlying rocks are stripped away by erosion. Over geological time scales these rocks are soluble in water. The fractures gradually enlarge as water moves through them and as the rock slowly dissolves. This process can produce openings up to the size of caverns but they are more commonly sub-millimetre to centimetre scale. The end result can be a sponge like aquifer with a high storage capacity and the potential for considerable volumes of water to move through it. Cave systems, if present provide localised pathways for the rapid movement of water. The network of fine cracks and small solution cavities form what is often a more pervasive aquifer that water can move through, generally at a much slower rate. A cave can act as collector drain, gradually picking up water along its length from the fine openings in the rock and then draining it away rapidly to a discharge point.

### The Water Cycle

Water in aquifers is generally not static; the flow is driven by gravity. It is constantly moving from areas where it enters the ground (recharge areas), through the aquifer and then eventually discharging back to the surface at lower points in the landscape (discharge areas). The seasonal cycle of wet season / dry season is one of the major influences on the movement of groundwater (see Rainfall, Recharge and Discharge). Recharge occurs during the wet season. This increases the amount of water stored in the aquifers and raises the groundwater levels. The groundwater constantly drains to discharge areas and water levels drop when recharge ceases.

## Rainfall, Recharge and Discharge



The graph above shows the water level recorded in a typical bore (RN34367) in the Oolloo aquifer as well as the daily rainfall over a two year period. Four time intervals over a Wet / Dry season cycle are described below and these illustrate how recharge and discharge vary depending on rainfall.

**Interval A** The early rains are lost either to evaporation or are used up in wetting the soil. No recharge takes place and water levels continue to fall as groundwater drains from the aquifer.

**Interval B** Increasing rain saturates the sub-soil, allowing the first recharge to occur. Groundwater levels stop falling as recharge and discharge are in balance.

**Interval C** This is the peak of the Wet season and recharge now exceeds discharge. This results in the water level rising. High groundwater levels result in greater discharge.

**Interval D** The major rains stop and recharge ceases. The rate of discharge progressively falls as groundwater levels drop.

The site received over 2000mm of rain during the 2005/2006 Wet compared with only 800mm during the following Wet season. Recharge and consequently water level rise was also correspondingly less. Note that the recharge for 2005/2006 had only partially discharged by the end of the 2006 Wet season.

## Recharge

Recharge is the process where water is added to an aquifer. It can occur by three main ways; diffuse, stream bed and point source (Figure 4). Diffuse recharge is the widespread downward seepage of rainwater through the soil and then into the aquifer.

Stream bed recharge occurs where the soil and rock beneath a stream is permeable enough to allow leakage down to an aquifer. The watertable must be lower than the riverbed otherwise leakage cannot occur. At present, stream bed recharge is restricted to a section of the Katherine River where it crosses the Oolloo Dolostone and then only during the late Dry season. In drier periods such as in the 1960's, watertables were generally lower and stream bed recharge was probably more extensive.

Point source recharge occurs where big conduits such as sinkholes or caves allow direct drainage of runoff into the aquifer (Plate 2). Such openings are more common in the Tindall Limestone.

The amount of recharge depends on rainfall. Higher rainfall seasons result in greater recharge and vice versa. It is also varies across the basin depending on the local geology, soil and vegetation types. Recharge is greatest where the formations outcrop or are close to ground level. In many areas the aquifers are blanketed by younger sedimentary rocks, comprising Cretaceous aged clay and sandstone. Recharge waters can pass through these formations but at a lesser rate than where the aquifer is unconfined. Recharge is correspondingly less in those areas. Finally a major portion of the Tindall Limestone is covered by the Jinduckin Formation. Recharge to the Tindall Limestone in that situation is negligible because most layers within the Jinduckin Formation are impermeable to water moving downwards.

On rare occasions aquifers can locally fill up to ground level, leaving no space for additional recharge. A recharge area can even become a discharge area if the groundwater level rises above ground level. This has been recorded from a few localities around Katherine following exceptionally heavy rains (Plate 3).

## Groundwater flow

Once water makes its way into the aquifer it flows under the action of gravity to lower parts of the aquifer. The geology of the basin has led to different flow patterns in the Oolloo and Tindall aquifers (Figures 5 and 6).

The Oolloo Dolostone is the uppermost formation and is overlain by Cretaceous sediments in places. They restrict recharge to the aquifer but do not completely stop it. Consequently the Oolloo acts as one continuous aquifer. The pattern of groundwater flow is relatively simple, heading from the south east to the lowest parts of the aquifer in the north west and discharging into the Daly River. A minor proportion discharges into the Katherine River but most flows to the Daly.

A more complex flow pattern occurs in the Tindall Limestone because it is the oldest formation and so is only exposed in a zone around the margins of the basin. Recharge is only possible in that zone because elsewhere it is confined by the Jinduckin Formation. Water tends to take the most direct path from recharge to discharge areas. This has resulted in at least six separate groundwater catchments, each with their own discharge zone. The main flow directions are parallel to the edges of the basin and towards the rivers where the groundwater discharges. The Roper, Katherine, Edith, Douglas, Daly (downstream of the Douglas) and Flora Rivers are the main discharge zones.

The Tindall Limestone is continuous across the basin but only a relatively small proportion of the groundwater flows through the confined section beneath the Jinduckin Formation. The aquifer is known to still be permeable even at hundreds of metres depth but the most direct route for the water is through the unconfined aquifer.

### Discharge

Groundwater returns to the surface at low points in the landscape. In the Daly Basin this is mostly along the rivers (Figures 5 and 6). Discharge is controlled by the two types of openings that make up the aquifers, described above. Water in the large conduits emerges from discrete springs such as Katherine Thermal Spring and Rainbow Spring (Plate 4). These are both cave-like openings and can have discharges up to 500 L/sec. Such springs are more common in the Tindall Limestone which is the most cavernous of the three Daly Basin formations.

A more common type of discharge is less visible and originates from the widespread network of fractures rather than from caves. It consists of seepage into the river beds, often over stretches that are kilometres in length. Such discharge zones are best detected by measuring stream flows during the Dry season at successive points along the rivers and noting any downstream increases in flow. The discharge zones shown on figures 5 and 6 include both stream bed seepage zones and discrete springs.

It is generally easier for water to get into an aquifer than it is to drain out of it. This is because the area over which recharge occurs is usually greater than the area through which discharge can potentially occur. Recharge takes place over a three to four month period but it usually takes a whole year or longer for that water to discharge. This maintains year round flow in the major rivers. Distinctive ecosystems rely on these permanent streams. These include both in-stream and riverbank flora and fauna (Plate 5).

## How much water is in the basin?

The Daly Basin aquifers are extensive and store a large volume of water. An estimate of the volume of groundwater stored in the basin is 350,000,000 megalitres (a megalitre is a million litres). The volume added each year as recharge has recently been estimated to be of the order of 1,000,000 megalitres. On average, discharge will equal recharge. The annual recharge is therefore small in comparison to the total storage. How much of this water is available for human uses such as agriculture and domestic water supplies? That is determined by competing users and is currently the subject of a Water Allocation Plan.

### Water availability

During the Dry season all river water is sourced from groundwater. The Daly, Katherine, Douglas, Flora and Roper Rivers flow throughout the Dry season. This is relatively unusual because the majority of streams in the Top End of Australia stop flowing early in the Dry season. The streams in the Daly Basin support a diverse flora and fauna as a result of their permanent flows. Sustainability of this ecosystem is a priority and is the main guiding principle behind water management in the basin.

Any extraction of groundwater will eventually result in a corresponding reduction in discharge to the river. In the case of a bore located on the river bank, the impact on the river could be almost immediate. With bores located at increasing distances from the river however the impact will be delayed and also spread over a period of time.

For those parts of the aquifers that are the most remote from a river the delay between pumping and its impact on the river can be of the order of 10’s to 100’s of years. The impact is of course also dependant on the rate at which water is pumped.

In order to maintain river flow in the Dry season, the watertable must be higher than the river bed. As it drops to river bed level, inflow of groundwater will cease. Once it drops below the river bed the flow can be reversed and the river will lose water to the aquifer. A large proportion of the groundwater is stored below a level beyond which any further lowering of the watertable would dry up the whole river in the Dry season. That amount of groundwater is essentially unavailable for use. The quantity that is available is equivalent to a proportion of the long term average recharge. That proportion will be determined on what is necessary to maintain the riverine ecosystem and to protect in-stream public outcomes such as fishing, boating, aesthetics, spiritual fulfilment etc. The proportions reserved will be based on available scientific information on groundwater dependent ecosystems and their water requirements. Such estimates must naturally be conservative because of our incomplete knowledge about environmental water requirements.

### How are water allocations determined?

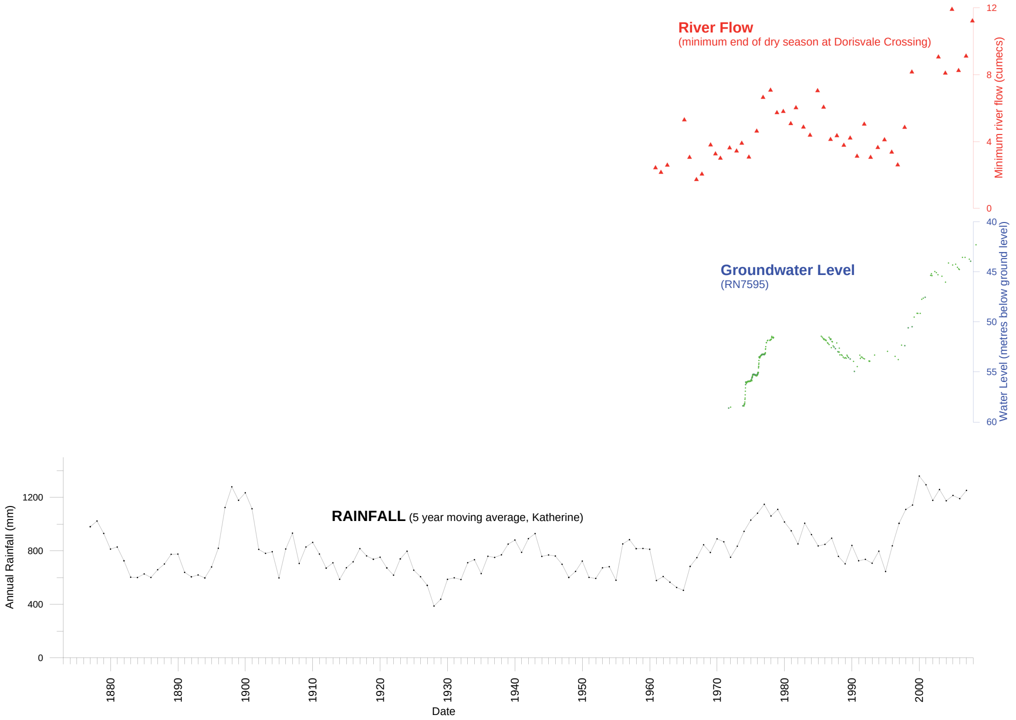
In order to determine the effects of water extraction on river flows and on groundwater levels, many factors must be taken into account. These include the properties of the aquifers, the degree to which the aquifers are connected to the rivers, rainfall, geology and soil type and the amount of water pumped from the aquifers.

As a first step in understanding the system, a simple water balance is commonly made. It attempts to match up the amount of water going into an aquifer with the amount leaving it over a specific period of time. This gives the order of magnitude of the various components of the water balance but it is too broad to be a basis for water allocations.

The real life water balance is highly complex because all of its components and the factors which affect them change both with time and location. Mathematical models that simulate the flow of groundwater through aquifers are commonly utilised because they can take account of some of the complexities. Models are normally calibrated by adjusting them till they fit historic groundwater levels or Dry season river flows. They can then be used to predict these under future pumping regimes and future rainfall scenarios. It is thus a useful tool for basing decisions about water allocations. Models are only an approximation of the groundwater system and are only as good as the state of knowledge of how the system operates. As that knowledge improves, so the accuracy of the model can also be improved.

One critical factor that has to be accounted for is climate change (see Abundant Water?). Since the mid 1970’s rainfall over the Top End has increased substantially. Groundwater storage and Dry season river flows have also increased correspondingly. The current situation with abundant water could easily be seen as the “norm”, were it not for rainfall and stream flow records prior to the 1970’s. Apart from such “long” term changes of the order of thirty years, rainfall and so recharge varies from year to year. Water allocations need to be flexible enough to take these variations into account.

## Abundant Water?



Both river flows and groundwater levels are closely related to rainfall. Since the mid-1970's, above average rainfall has resulted in record high groundwater levels and high end of Dry season river flows. Note that the lowest recorded flow for the gauging station shown above was 2.2 cumecs in October 1965. This compares to 9.8 cumecs during September of 2008. Water has been abundant for the last 30 years and "climate change" models suggest that the Top End will remain wetter. The possibility that the rainfall pattern will revert to the lesser amounts seen from 1950 to early the 1970's must always be considered.

*This graph compares groundwater levels, end of dry season river flows and rainfall. River flows have been measured since 1960 and groundwater levels since 1971. The rainfall record however extends back to the 1870's at Katherine.*

## Water quality

The majority of groundwaters in the basin fall within the drinking water guidelines set by the Australian National Health and Medical Research Council, 2004 (http://www.nhmrc.gov.au). All groundwaters contain dissolved salts derived from natural sources. In the case of aquifers in carbonate rocks, such as the Tindall and Oolloo aquifers, calcium, magnesium and bicarbonate are the dominant dissolved salts. Rainwater which tends to be slightly acidic reacts with the limestone and dolostone, releasing those salts. The main effect is that the waters are “hard”, meaning that soap does not lather well and scale can build up in hot water pipes and other plumbing fittings.

In a few localities, other naturally occurring constituents of the groundwater present water quality issues. As previously mentioned, parts of the Jinduckin Formation contain the minerals anhydrite (hydrated calcium sulphate) and halite (sodium chloride). Aquifers adjacent to these rocks can contain excessive amounts of calcium, sodium, sulphate and chloride. Many bores just west of Katherine have groundwaters that exceed guideline values for human consumption for these individual salts as well as for salinity (the sum of all individual salts). Similar problems occur in the Tindall aquifer south of Mataranka. In that case the source of the salts is thought to be an equivalent formation to the Jinduckin Formation in the adjacent Georgina Basin.

Also encountered locally is an excess amount of radium, a naturally occurring radioactive element. This is mainly restricted to an area just west of Katherine and has only been detected in the Tindall Limestone, immediately below the contact with the overlying Jinduckin Formation. Mineralisation in the latter formation is thought to be the source of the radium. Groundwater from areas known to have elevated radium levels and from aquifers in similar geological settings should be tested for radium before being used for human consumption.

Aquifers in carbonate rocks typically contain large conduits such as sinkholes and caves. These can provide rapid access to the groundwater from surface waters and any man-made contaminants they may contain.  The filtering effect of the soil that normally takes place when other types of aquifer are recharged is bypassed. The Daly Basin aquifers and the rivers that are fed by groundwater discharge are therefore very susceptible to contamination. To date there have been no recorded instances of groundwater pollution but the risk should be kept in mind when planning urban drainage, fuel storage tanks, waste disposal sites, septic tanks, storage and management of agricultural chemicals and any feature or activity with the potential to have adverse impacts on groundwater.

## Glossary

**aquifer:** A body of rock or sediment which holds and allows water to move through it and which is capable of yielding usable quantities of groundwater to boreholes and or springs.

**basalt:** An igneous rock extruded as a lava.

**baseflow:** The proportion of water flowing in streams and rivers that comes from groundwater. Stream flow during at the end of the Dry season may be virtually all groundwater.

**calcium carbonate:** A white chalky mineral that makes up most sea shells. It can also be precipitated directly from seawater or from groundwater.

**carbonate rock:** A rock such as limestone or dolostone, consisting largely of the carbonate minerals; calcium carbonate or calcium magnesium carbonate.

**confined aquifer:** A confined aquifer occurs where an aquifer is overlain by a confining bed. The confining bed prevents vertical movement of the groundwater. Such aquifers are usually completely saturated with water which is commonly under pressure. Therefore when a bore intersects the aquifer, water rises up the bore. If the pressure is sufficient to drive the groundwater above the ground level, the bore is called artesian.

**diffuse recharge:** The widespread downward seepage of rainwater through the soil and then into the aquifer.

**discharge:** Outflow of water from an aquifer.

**dolostone:** A sedimentary rock composed mainly of the mineral dolomite (calcium magnesium carbonate).

**ecosystem:** A system made up of a community of animals, plants, and bacteria interrelated together with its physical and chemical environment.

**evaporite minerals:** Minerals crystallised from a saline solution as a result of extensive evaporation of a water body.

**fractures:** Cracks or fissures within rocks.

**granite:** An igneous rock that solidified deep within the earth. It is commonly made up of coarse crystals of the constituent minerals.

**greywacke:** A sedimentary rock consisting of angular fragments of quartz, feldspar, and other minerals set in a muddy base.

**groundwater:** Water beneath the surface of the earth which saturates the pores and fractures of sand, gravel, and rock formations.

**groundwater dependent ecosystems:** A community of plants and animals that rely partially or completely on groundwater for its existence.

**lagoon:** A shallow body of water, especially one separated from a sea by sandbars or reefs.

**limestone:** A sedimentary rock composed mainly of the mineral calcite (calcium carbonate).

**point source recharge:** Water entering an aquifer from a discreet point source such as a cave.

**recharge:** Water added to an aquifer.

**salinity:** The concentration of mineral salts dissolved in water. It may be expressed in terms of a concentration or as electrical conductivity.

**sandstone:** A sedimentary rock composed of sand grains cemented together.

**siltstone:** A sedimentary rock composed of silt sized particles.

**sinkhole:** A depression in the Earth's surface caused by collapse of overlying soils or rock into pre-existing cave systems formed by dissolving of underlying limestone. Drainage is provided through underground channels that may be enlarged by the collapse of a cavern roof.

**solution cavity:** Opening in rocks produced by dissolution, commonly of limestone or dolostone.

**spring:** An area where there is a concentrated discharge of ground water that appears as a flow of water at the surface.

**stream bed recharge:** Water added to an aquifer through permeable zones in stream beds.

**surface water:** Water that is on the earth's surface, such as in a stream, river, lake, or reservoir.

**tectonic:** Relating to structural deformation of the earth's crust.

**unconfined aquifer:** An unconfined aquifer is a permeable formation which extends from the land surface down to a confining base. It is generally partly filled with water and open to air pressure above. When penetrated by a bore the water remains in the bore at the same level at which it was struck. This is because the water pressure at the water table is at atmospheric pressure. The water surface in such an aquifer is called the water table.

**water allocation plan:** A plan devised to divide water between different users and to manage its use.

**watertable:** The water level of an unconfined aquifer, below which the pore spaces are generally saturated.

# Further Reading

## Groundwater

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## Radium

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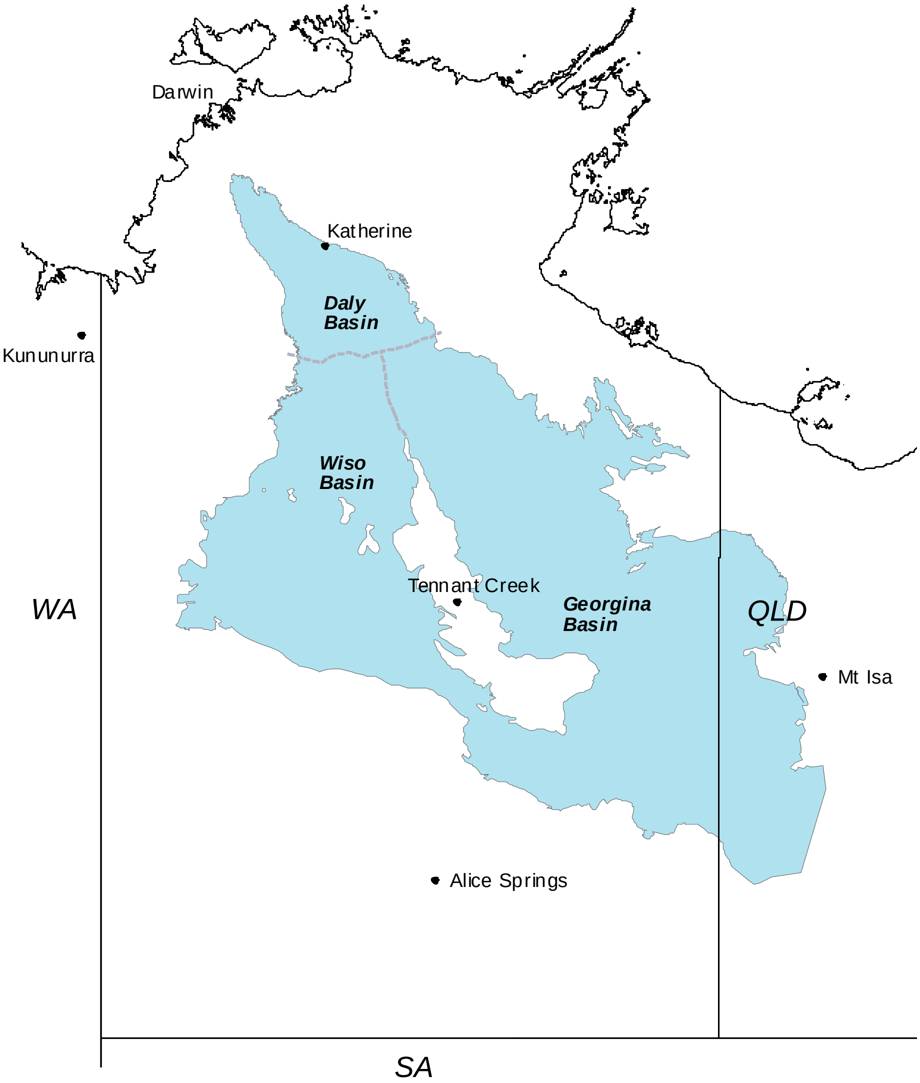

Figure 1 Limestone basins in the Northern Territory

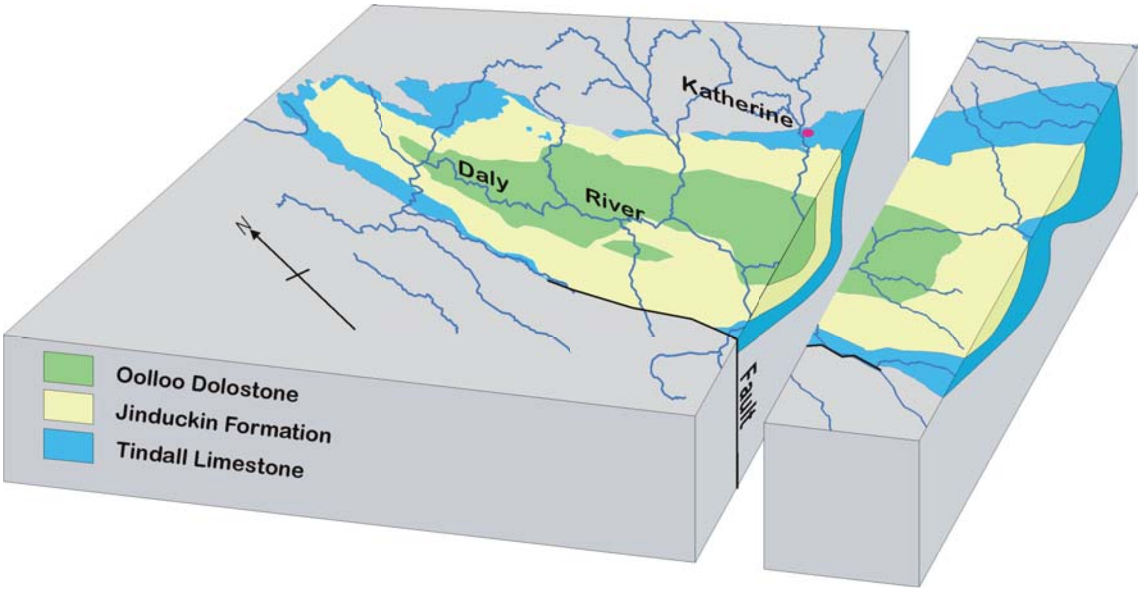

Figure 2 3D view if the Daly Basin (overlying Cretaceous rocks not shown)

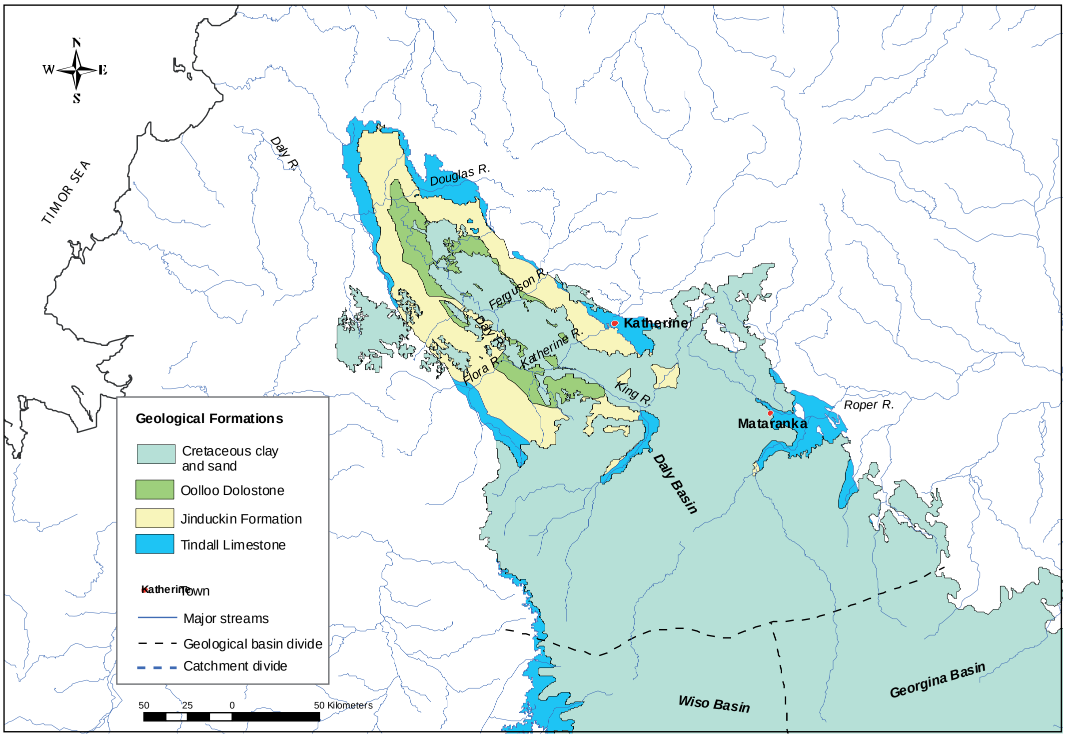

*Figure 3 Cretaceous rocks overlying Daly Basin aquifers generally restrict recharge*

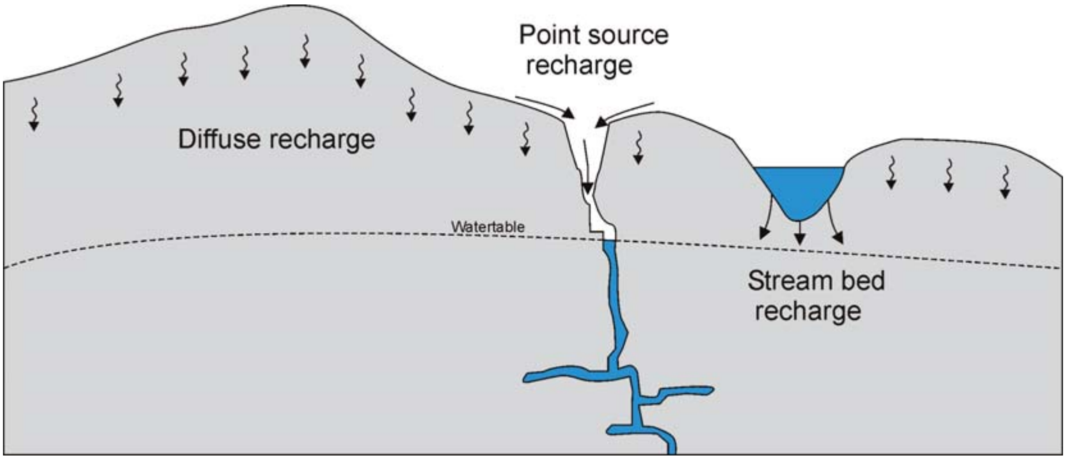

*Figure 4 Recharge mechanisms*

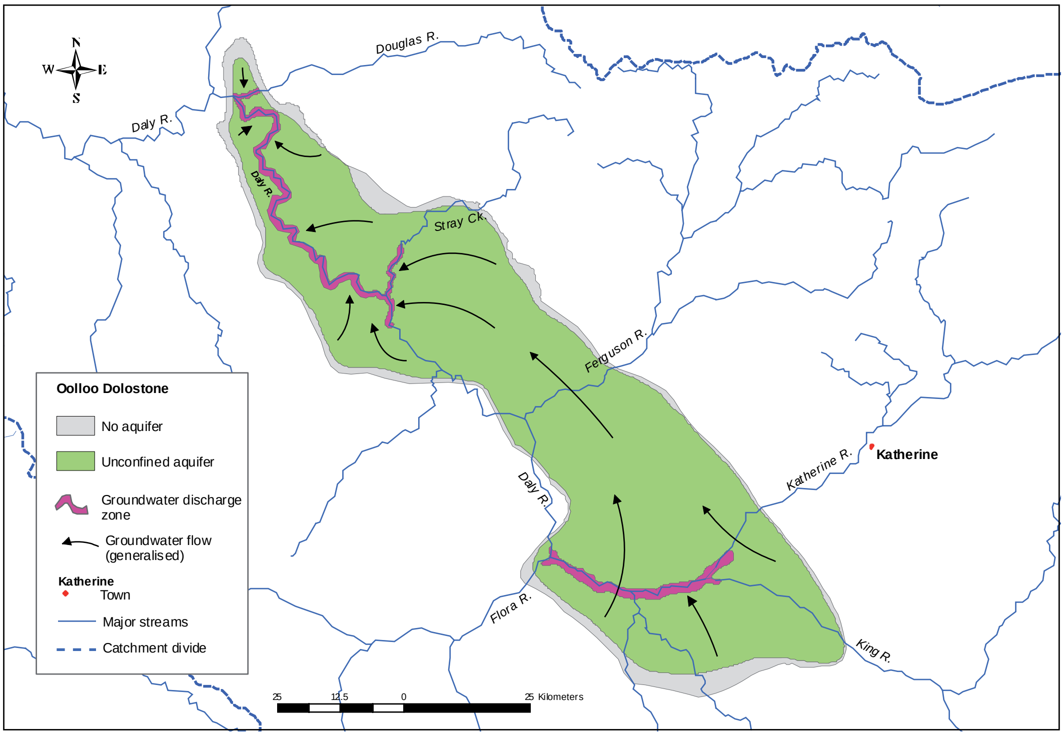

*Figure 5 Oolloo aquifer and generalised groundwater flow directions*

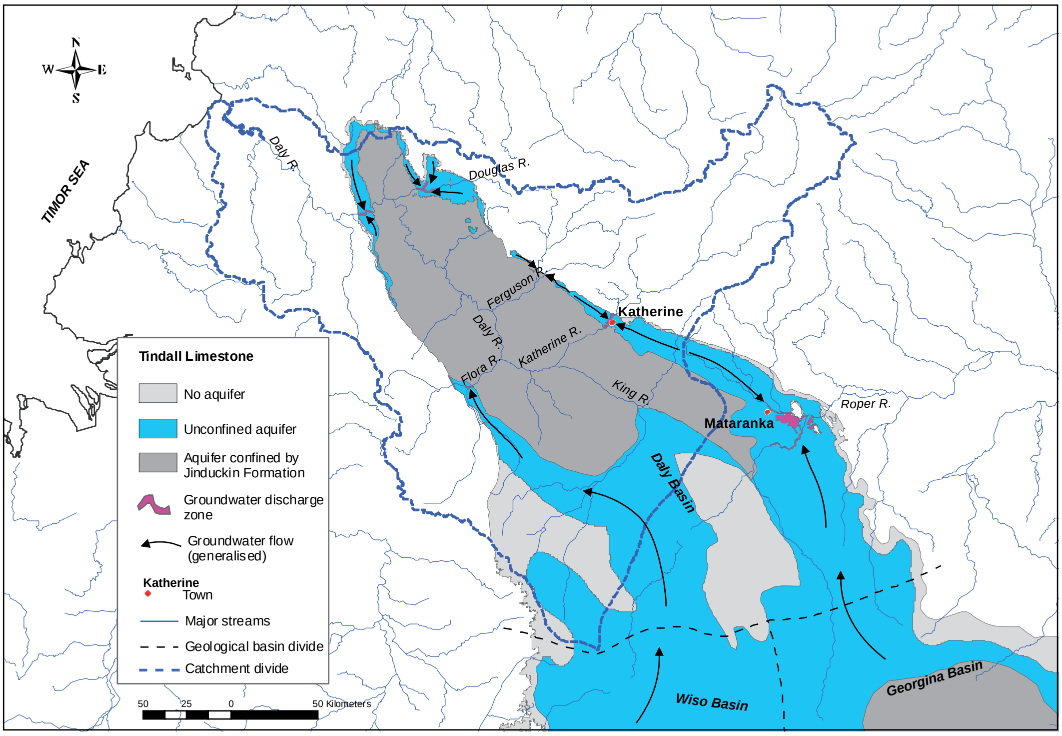

*Figure 6 Tindall aquifer and generalised groundwater flow direction*

*Oolloo Dolostone*

*Jinduckin Formation*

*Tindall Limestone*

*Plate 1 The three geological formations from the Daly Basin (photos S. Tickell).*

*Plate 2 Water pouring into a small "sinkhole" in the Oolloo Dolostone (photo D.Karp).*

*Plate 3 A temporary lake formed largely by groundwater discharge following exceptionally heavy rains, March 2004, Uralla Rd., Katherine (photo G. Atkinson).*

*Plate 4 Rainbow spring at Mataranka. Groundwater emerges from a half metre wide solution cavity in Tindall Limestone (photo A.Knapton).*

*Plate 5 The Daly River and its tributaries support a distinctive ecosystem (photo Tourism NT).*