NORTHERN TERRITORY BRANCH OF IAH AUSTRALIA

Tufa Dams of Northern Australia

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11 April 2011

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1. Background

In the north of Australia, karstic carbonate rocks, with extensive aquifers occur in Lower Palaeozoic and Proterozoic aged carbonates. Their greatest extents occur in the Daly, Wiso and Georgina Basins of the Northern Territory (Figure 1). In many areas these aquifers are overlain by Cretaceous aged sedimentary rocks which form a semi-confining layer. This is the case for a broad area extending from the Daly Basin to the northern Georgina Basin.

The carbonate formations are hard and fractured. Fractures are commonly enlarged by solution of the carbonate rock often to the extent that cave systems are locally present. A more pervasive secondary porosity can be formed by selective dissolution of dolomite crystals. Crystalline dolomite is partially silicified by weathering. Crystals that have not been replaced by silica are then dissolved by acidic recharge waters, leaving a porous rock that resembles “sugary” sandstone. This can form a sheet like aquifer which overlies and is in hydraulic connection with the carbonate rock below.

These karstic aquifers are capable of yielding quantities of water, sufficient for town supplies and major irrigation. The flow systems in these aquifers are of regional to intermediate scale. One extreme is the Georgina Basin with groundwater flow paths of the order of several hundred kilometres. These aquifers discharge via springs commonly with individual flow rates up to several hundred litres per second. Prominent examples include the springs of the Flora, Roper and Gregory Rivers (Tickell 2008).

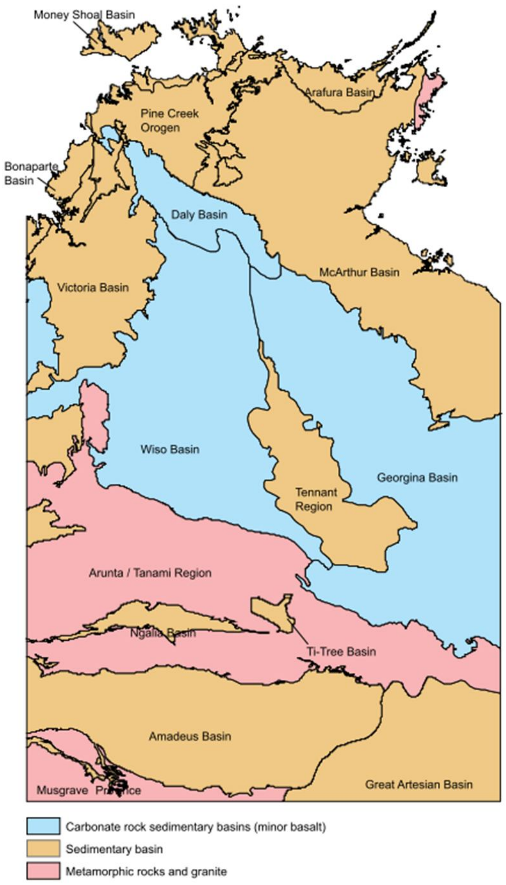

Figure 1Geological Regions

2. Introduction to Tufas

Ambient temperature freshwater carbonates precipitate as surface deposits within karstic stream, lake and swamp environments (tufas) and in subterranean situations (speleothems). Although physico-chemical mineral precipitation contributes significantly to both kinds of deposit, there is a clear spatial association between the development of tufa deposits and the occurrence of microbial biofilms. To add to the inherent complexity, there is considerable interplay between biological and physical processes to consider. Water velocity and turbulence will strongly affect biofilm colonization and may damage the community, thereby affecting carbonate precipitation rates. Exchange of carbon dioxide gas at the air–water interface is an important conditioner for precipitation in vadose systems but will also occur within surface systems as a consequence of photosynthesis.

Tufas and speleothems share the same soil derived meteoric water supply, represent zones of deposition of calcium ions chemically eroded from the same geological sources and produce laminated deposits which are superficially similar. In passing from cave environments via resurgences (Figure 2) into surface waterways, water passes down an interconnected hydrological system at any point in which the conditions necessary for calcite precipitation may be achieved.

On a regional scale the occurrences of tufas and speleothems are both controlled by water table fluctuations. Typically, tufa deposition is associated with predominantly high water tables and are most effective as bio-constructors where spring fed streams are not subjected to spate conditions. Similarly, tufa developments are severely impaired by fluctuating water tables associated with increasingly arid climatic cycles. Limitation on surface carbonate precipitation is consequently derived from the necessity for biofilm development combined with the equal necessity of adequate supply of dissolved calcium and carbon, which must be present at least in part as carbonate. The latter requirement of sufficient $Ca^{2}_{(aq)}$ and $CO_3^{2+}{}_{(aq)}$ ionic activity demands that these ions are not lost from solution before resurgence, making it likely that tufas will develop best where caves are flooded. Curiously, these elevated tables are frequently encouraged by the tufa growth itself as a consequence of the valley bottom ponding and back flooding caused by barrage development.

(Note: Section 2 and Figure 2 extracted from Pedley et al 2010)

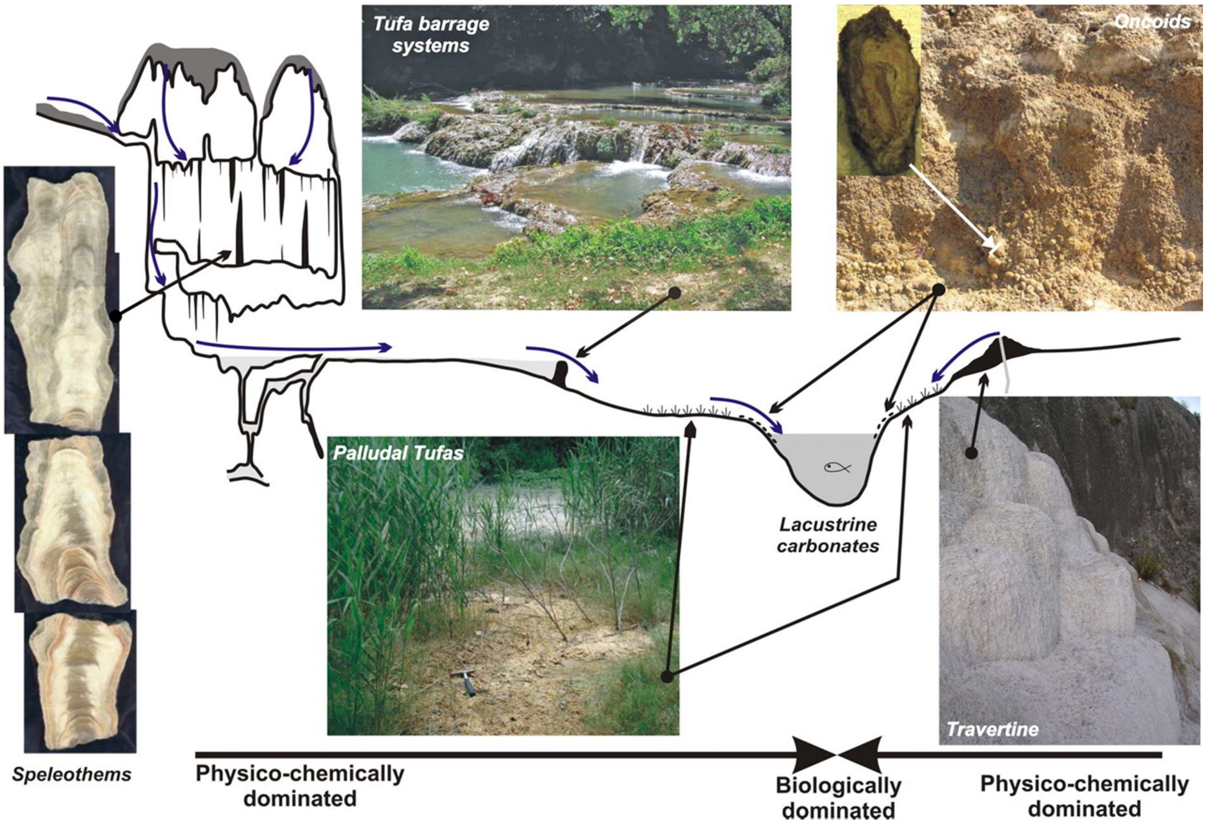

Figure 2A schematic diagram of terrestrial carbonate precipitation.

3. Tufa Dams (or barrages) of Northern Australia

Tufa dams occur within many of the drainage systems of northern Australia. The locations where the largest tufa dams occur are shown on Figure 3. These dams are located on the Flora, Roper and Gregory Rivers (and their tributaries). These rivers are not normally subject to spate conditions. However, on the occasions when large floods occur, erosive damage to tufa dams can be considerable. Flow in these rivers is sustained during the dry season of northern Australia by discharge from regional aquifers in carbonates (primarily dolomite) of the Georgina, Wiso and Daly Basins. In the Georgina and Wiso Basin groundwater levels do not vary greatly. Tyson et al (1993) reported that the water level in bore RN471 which was drilled into carbonates of the Georgina Basin varied by only 0.2 meters between 1953 and 1992. Adjacent to spring discharge points the land is relatively flat, water tables in the aquifer are high and as a result caves are flooded. All these conditions create the ideal environment for the formation of tufa dams.

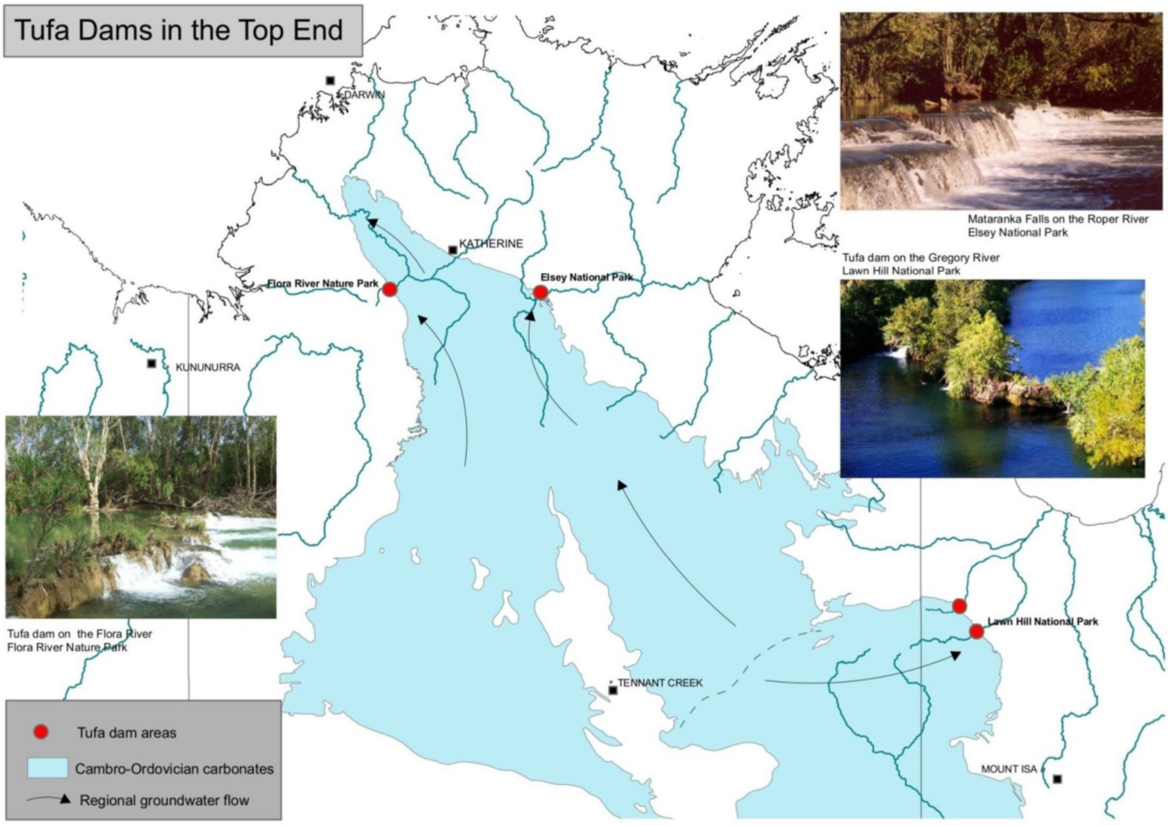

Figure 3Tufa Dams of northern Australia

Spring-fed rivers in tropical northern Australia form an array of tufa and related freshwater carbonate deposits. One of these deposits, calcite rafts, is precipitated at the water–air interface principally as a consequence of carbon dioxide degassing and evaporation. Calcite rafts have been reported in cave environments but have not been described in detail from fluvial systems. Observations using scanning electron microscopy coupled with water chemistry data reveal that they form by a combination of physical, chemical and biological processes. They grow downwards into the water column and form a dentate lower surface, while a flat upper surface occurs at the water–air interface. The rafts are readily inhabited by microorganisms, particularly diatoms, which frequently become entombed by calcite as the rafts develop. The decay of the biological material leaves voids, creating a pock-marked texture. The rafts are subject to secondary calcite growth along the crystal edges. Once they become submerged in the water column after disturbance of the water surface, they may become completely covered by this overgrowth, creating a homogeneous veneer. The rafts form in quiescent settings, principally behind tufa dams in large, lake-like water bodies along each river. Therefore, they can be used in conjunction with adjacent exposures of other tufa facies to decipher palaeohydrological conditions. Although the rafts are extremely thin and fragile, they are readily preserved within fossil waterhole facies, and their occurrence has been identified in rocks from the Quaternary to the Tertiary (Taylor et al 2004).

The build-up of carbonate material on a tufa dam during the dry season can adversely affect the accuracy of flow information gained from river gauging stations that use a tufa dam as a control. Flows are derived from height data collected by the gauging station instrumentation. As water levels increase during the dry season derived flows increase, even though flows are decreasing. This can be seen from the plots of height data given for the Flora River at gauging station G8140044 in Figure 4.

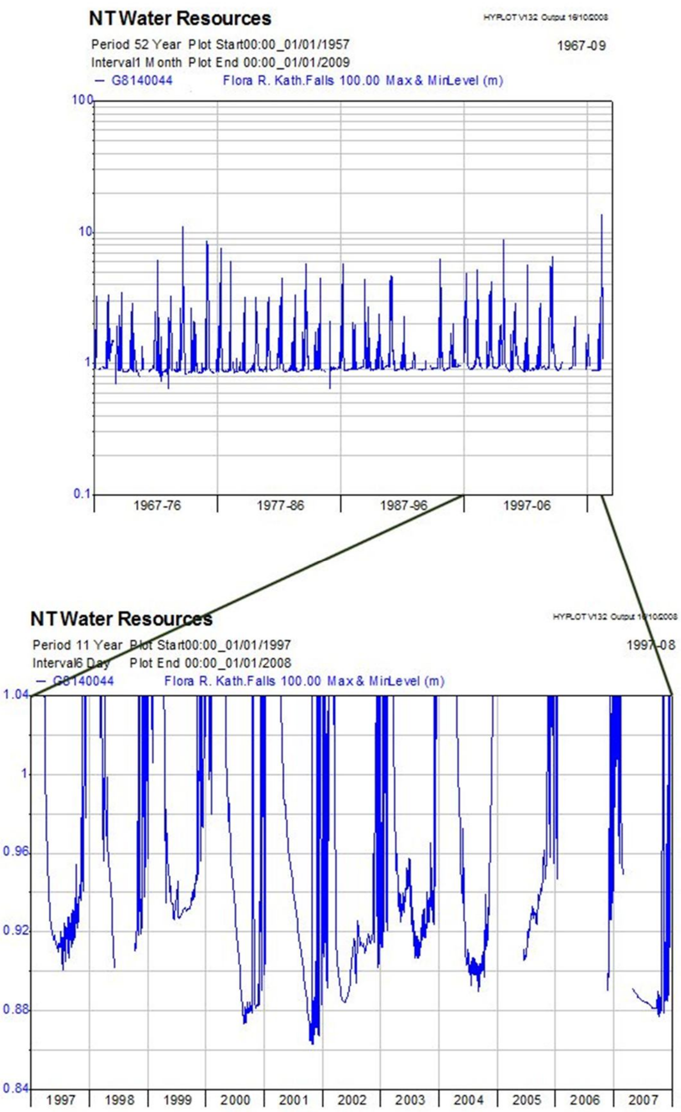

Figure 4Measured river levels at G8140044 on the Flora River

4. Tufa Dams on the Flora River

The natural springs that feed the Flora River help maintain a high flow rate, even during the dry season (between 250 to 350 million litres per day). The springs are maintained from discharge from the karstic aquifer that has developed in the Cambrian Tindall Limestone. The aquifer that sustains these springs discharges water that is recharged over an area that extends for over 250 kilometers to the south of the Flora River (refer Figure 3). The springs contain high concentrations of calcium bicarbonate that is dissolved when water passes through the limestone (refer Table 1).

Table 1Water Chemistry Flora River springs

TDS (mg/l)	Temp (deg.C)	Sodium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Hardness (mg/l)	Chloride (mg/l)	Sulphate (mg/l)	Bicarb (mg/l	Fluoride (mg/l)	Silica (mg/l)
506	34	17	105	36	410	22	28	517	0.3	42

When the flow of mineral-rich water in the river is interrupted, for example by plant debris or rock bars, carbon dioxide is lost from the calcium bicarbonate, and calcium carbonate is precipitated onto the obstruction. In time this becomes the tufa that forms the picturesque dams and cascades for which the river is known. Tufa dams are well developed at intervals along the Flora River downstream from the springs. The tufa formations are fossil-rich and contain gastropod (snail) and lamellibranch (mollusc) remains of scientific interest. In the still waters of the waterholes upstream of these dams a "scum" of fine calcium carbonate crystals can sometimes be seen floating on the water.

Townsend et al (2002) noted that the exceptionally clear waters of the Flora River are noteworthy; for example, in July the euphotic depth (depth of water that is exposed to sufficient sunlight for photosynthesis to occur) was 15 metres and turbidity was 0.9 NTU. They noted that this must rank the Flora River amongst clearest rivers globally.

Kathleen Falls is a tufa dam that spans the breadth of the river (Figure 5).

Figure 5Kathleen Falls - a Tufa Dam on the Flora River

5. Tufa Dams on the Roper River

Groundwater is primarily sourced from rainfall infiltrating into the ground. When a body of rock is sufficiently permeable to transmit groundwater and to yield useable quantities of groundwater to bores and springs it is called an aquifer. A large regional Cambrian aged carbonate aquifer extends from Queensland across a large part of the Territory. Part of the upper Roper River catchment overlays this aquifer (refer Figure 2). The groundwater movement is directed towards:

- wetlands located in and around Elsey National Park
- springs along the Roper River such as Rainbow, Bitter and Fig Tree Springs
- seepage to the beds in the upper Roper River, lower Waterhouse River, Roper Creek and Elsey Creek

The thermal pool at Mataranka is the most famous of the springs discharging at approximately 25 million litres per day. Groundwater discharge maintains dry season flow in the Roper River which in turn maintains dependent ecosystems along its length. Generally the dry season flow in the Roper River maintained by discharge from springs and seepage in the Mataranka region is between 200 and 500 million litres per day (Knapton 2009).

Tufa deposits are extensive both in and adjacent to the Roper River in Elsey National Park. Tufa formation is complex but results from calcium carbonate precipitation under conditions where water exceeds calcium carbonate saturation. In the Mataranka region the aquifer in the underlying Tindall Limestone is the source of the calcium carbonate. The point where deposition commences is generally downstream of springs where small pressure changes occur in the water often due to obstructions.

Deposits of tufa have formed waterfalls across the Roper River (Figure 6), along Elsey Creek (Figure 7) and along the south bank of the Roper River within Elsey National Park (Figure 8).

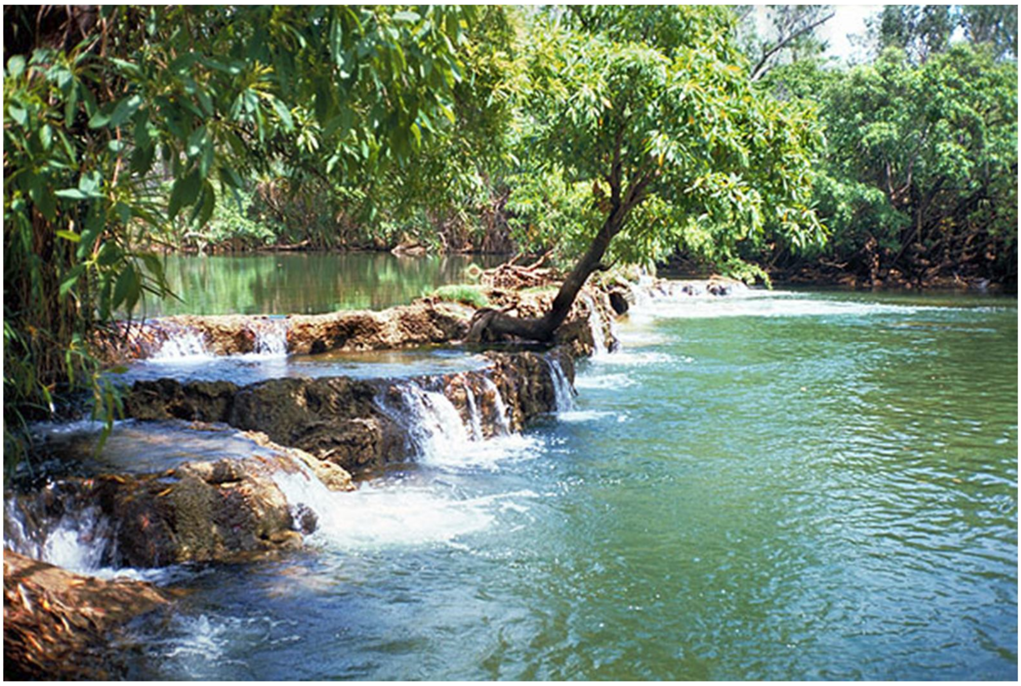

Figure 6Mataranka Falls a tufa dam on the Roper River

Figure 7Tufa formed along Elsey Creek (Karp 2008)

Figure 8Tufa formed in the swamp/spring area located in Elsey National Park (Karp 2008)

In the Daly Basin the Tindall Limestone contains water of low sodium, chloride, sulphate and TDS (refer Table 1). In the Elsey National Park area however, groundwater has elevated concentrations of these parameters compared to Tindall limestone water found elsewhere in the Daly Basin. Bore 32964 drilled approximately 20 kilometres north of Elsey National Park show typical Tindall Limestone water with low sodium, chloride and sulphate. Bore 31953 located south of Elsey National Park is dominated by groundwater from the carbonate aquifers of the Georgina Basin with elevated sodium, chloride, sulphate and TDS. These variations in water quality are shown in Table2.

Table 2Typical groundwater quality for Tindall Limestone aquifers (Karp 2008)

Bore	pH	TDS	K	Ca	Mg	Na	Cl	SO_4	SiO_2	HCO_3	Date
32964	7.6	332	3	50	30	9	15	12	29	353	17/072001
25600	8.0	705	9	44	61`	117	6	99	35	201	23/11/1987
31953	7.3	952	22	121	61	137	178	200	40	543	18/08/1999

Knapton (2009) modelled the discharge from the carbonate aquifers of the Georgina and Daly Basins into the Roper River in the vicinity of Elsey National Park for the period 1900 to 2009. The results are plotted in Figure 9. The modelled output and gauged data indicate that groundwater discharge into the Roper River in recent years has been twice the discharge that occurred during the period 1900 to 1970. This is due to the increased rainfall that the area has experienced. Knapton (2009) noted that the rainfall and rainfall residual mass curves for Katherine and Mataranka were quite similar and that the trend from 1996 – 2009 showed a period with rainfall approximately 350 mm per year above the long term average (Figure 10).

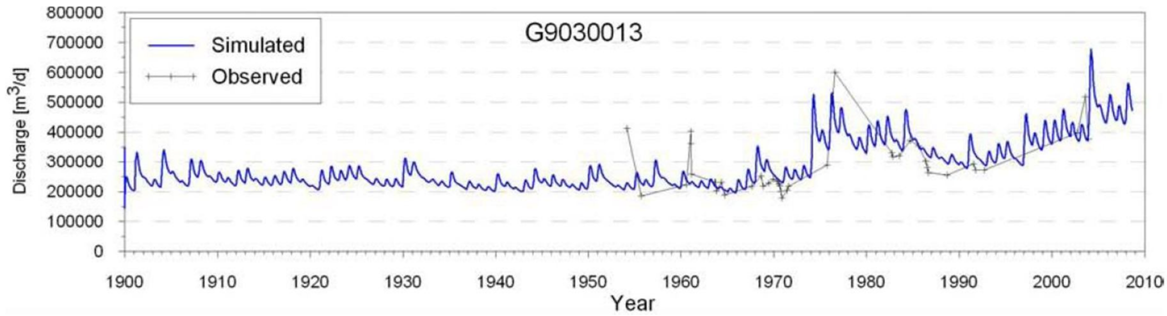

Figure 9Groundwater discharge into the Roper River in the vicinity of Elsey National Park

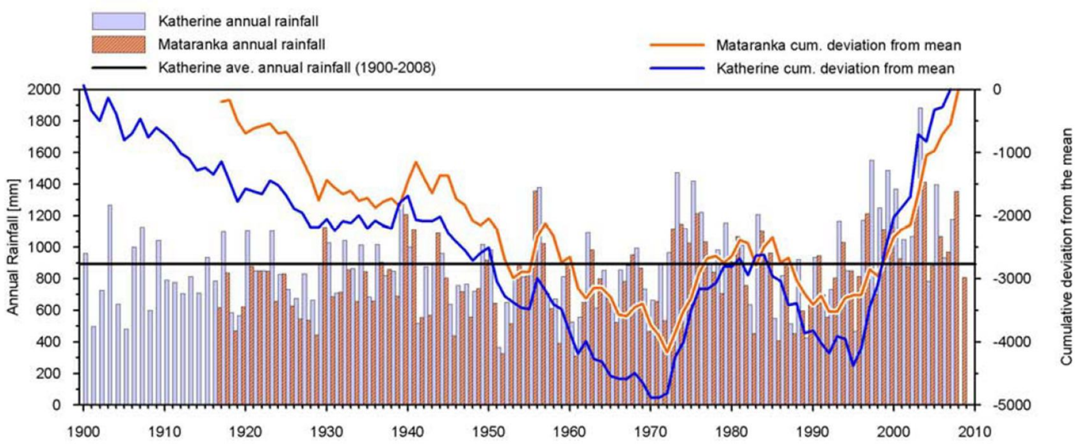

Figure 10Annual rainfall data for Katherine and Mataranka

6. Tufa Dams on the Gregory River

Springs discharge from the aquifer developed in the Cambrian Thorntonia Limestone and Camooweal Dolostone where the Gregory River and its tributaries have cut down through these formations. Where they river flows over obstructions such as rocks or vegetation debris it has deposited tufa. In places it has gradually built up to form small dams.

In the Riversleigh area of Lawn Hill National Park, much younger pale-grey limestones, deposited between 25 and 15 million years ago in Tertiary times, have been distinguished in a number of places lying on top of the older Cambrian limestones. The younger limestone - the Carl Creek Limestone - is thought to have been deposited in small rainforest lakes that flourished in the wetter climate of the time. This limestone has become famous for the fragments of fossil vertebrate animals it contains. Early relatives of today's fauna fell, or were washed into those lakes, and were preserved for posterity in the lime-rich sediments. Fossils include marsupial lions, carnivorous kangaroos, diprotodontids, huge pythons, platypus, crocodiles and bats.

The earliest Carl Creek sediments were formed by precipitation from highly calcareous fresh waters issuing from springs located along the Thorntonia limestone front. Over time these tufa deposits were broken down into rock fragments and were then deposited downstream by the river systems to form breccias (angular rock fragments), conglomerates (rounded rock fragments) and clastic sediments (fine grained). These sediments were deposited at various intervals along the river valley and in ephemeral swamps. In places the Carl Creek Limestone was laid down upon the karstic surface of the Thorntonia Limestone.

Aboriginal occupation at Lawn Hill dates back at least 17,000 years and may extend beyond 30,000 years. The Traditional Owners, the Waanyi people, know this country as Boodjamulla or the Rainbow Serpent country. According to the Waanyi people, Boodjamulla, the Rainbow Serpent, formed the Lawn Hill Gorge area and created the permanent spring water. To the Waanyi people, Lawn Hill Gorge is a sacred place used only for ceremonial and celebratory purposes. They believe that if you tamper with the water, pollute it or take it for granted, the Rainbow Serpent will leave and take all the water with him. (http://www.derm.qld.gov.au/parks/boodlamulla-lawn-hill/culture.html).

In the Gregory River and its tributaries tufas currently form in dam, cascade and pool/waterhole environments. Each environment is represented in the morphostratigraphical record by a specific combination of tufa geomorphic units and facies associations. A diverse array of tufa facies is present, including microphytic, larval, calcite raft, macrophytic and allochthonous types. Preservation of particular karst tufa facies is thought to reflect the strength of monsoonal floods. A strong monsoon is represented by an abundance of flood indicators such as the allochthonous phytoclastic, lithoclastic and intraclastic tufa facies. Evidence of weak monsoons or a prolonged absence of floods may include oncoids, calcite rafts and thick accumulations of fine carbonate sediments. The history of the Australian monsoon is not fully understood. However, tufa deposits, which record terrestrial climate information, have been preserved throughout northern Australia and hold great potential for reconstructing the region's climate history (Carthew et al 2006).

Generally the dry season flow in the Gregory River and its tributaries that is maintained by discharge from springs and seepages from the karstic carbonate aquifer is likely to be between 150 and 350 million litres per day.

Water quality data for the Gregory River and its tributary Lawn Hill Creek is presented in Table 3. The data represents the median of chemical analyses undertaken on samples collected at gauging stations 912103A on Lawn Hill Creek and 912105A on the Gregory River.

Table 3Water quality data for Lawn Hill Creek and Gregory River

River	TDS (mg/l)	Sodium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Hardness (mg/l)	Chloride (mg/l)	Sulphate (mg/l)	Bicarb (mg/l	Fluoride (mg/l)	Silica (mg/l)
Lawn Hill Creek	299	4	43	47	297	7	3	354	0.1	18
Gregory River	310	5	50	45	309	7	4	370	0.2	19

Figure 11Indarra Falls – a tufa dam on Lawn Hill Creek (a tributary of the Gregory River)

7. References

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