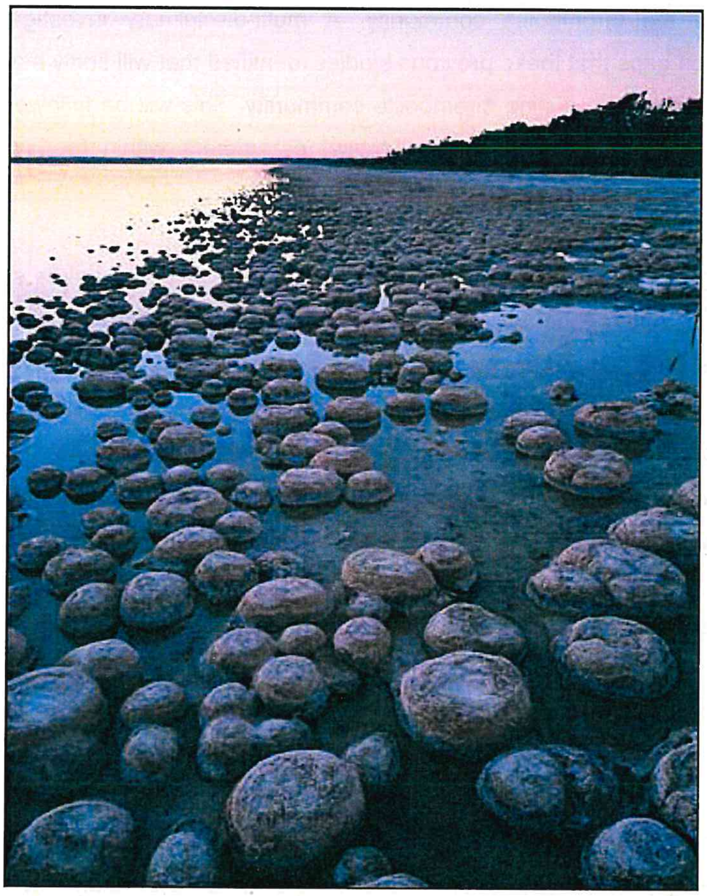
Monitoring and Threat Assessment Strategy for the Thrombolite Community of Lake Clifton.



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Summary.

The Lake Clifton thrombolite potential Threatened Ecological Community (or TEC) and its surrounding habitat is under pressure from numerous environmental threats, including increasing salinity, greater nutrient inputs, climate change and declining water levels, as well as increased human visitation (Moore 1991). Several hydrogeological (e.g. Commander 1988, Barr 2003), geochemical (e.g. Moore and Turner 1989, Davies and Lane, 1996, Knott et al. 2003, Luu et al. 2004) and biological (e.g. Moore et al. 1984, Burne and Moore 1987) studies have characterised the physiochemical dynamics of Lake Clifton and its catchment, identifying potential threats within the catchment to the thrombolite community. A multi-disciplinary investigation program is proposed, based on gaps that these previous studies identified that will firstly asses the age, size, diversity, and health of the existing thrombolite community. This will be followed by robust, long term monitoring of hydrological and geochemical parameters within the system, which will scrutinise threats to the microbialites.

Physical mapping of the thrombolite communities within the Yalgorup Lakes system and direct isotopic ($\delta^{13}C$, $\delta^{18}O$) and chronological (^{14}C - radiocarbon) investigations of the specified sections of the thrombolite community from Lake Clifton need to be undertaken. This will allow for the assessment of the thrombolites age, health, extent and the recent (Holocene) environmental history. Examination of deuterium ($\delta^{2}H$) in ground and the lake's interstitial waters, combined with carbon isotopic ($\delta^{13}C$) analysis of the dissolved inorganic carbon (DIC) within those waters, will allow for the flow of freshwater into the eastern portion of the lake to be better quantified and monitored. This will elucidate the nuances of the interaction between Lake Clifton and the underlying hypersaline groundwater. Comparisons can also be made to previous isotopic data sets collected by Moore and Turner (1989) to clearly establish the state and extent of ecological/hydrological changes that are currently occurring within the lake system and catchment. This will be used to asses the potential for an increasing threat to the thrombolites from altered hydrology. Monitoring the dynamics and quality of the fresh water inflow from the east, is important, as it has been identified as the likely source of the Calcium that is critical to the survival and the growth of the thrombolites. Quarterly or preferably monthly analysis of groundwater and lake water geochemical characteristics, including pH, Eh, salinity (TDS), anions, cations, alkalinity, acidity, phosphorous and nitrogen will allow for alterations in lake water composition to be identified. Also the hydrological dynamics of the lake, including alterations of inflows, such as increasing influx of saline groundwater verses surface runoff can be assessed. The results of these investigations will likely also allow for an assessment of the current and future impact to the lake and the thrombolites from increasing threat due to land use practises in the catchment.

1. Introduction.

Lake Clifton is the northeast member of a series of north-south elongated lakes located in the Yalgorup National Park, between the Peel-Harvey Estuary and the Indian Ocean (Fig 1). It is the second largest in the system, measuring approximately 21.5km long by 1.5km wide, with the water body covering approximately 18km^2 in maximum extent (Commander 1988). Most of the lake is less than 1.5m deep, with certain areas up to 4.5m deep. Essentially the lake can be divided into three basins; the northern, which is the deepest, the middle and the southern (Knott et al. 2003). Both the northern and middle basins are permanent while the southern basin is ephemeral, typically drying out in summer. Within the littoral margins of Lake Clifton is a community of thrombolites, that formed by biologically influenced precipitation of a particular form of calcium carbonate, termed aragonite in a coastal brackish lake (Moore and Burne 1994). The thrombolites community, which is the biggest in the Southern Hemisphere is situated in a zone about 15m wide on the eastern side of the lake, occupying a total area of over 4km^2 (Moore 1991). Only a small isolated colony has been observed on the western shoreline at the northern end of the lake (Moore et al. 1984). The thrombolites exhibit a wide range of external morphologies including conical, domical, discoidal and tabular forms (Moore 1991), which vary in width, height and morphology, with the largest up to 1.3m high, and diameters ranging between 20 and 150 cm.

Morphologies are controlled primarily by fluctuations in water depth, variations is sedimentation rates, and the prevailing winds and currents (Moore 1991). A wide range of thrombolite morphologies such as, conical, domical, discoidal and tabular formations (Fig. 2) have been identified (Moore and Burne 1994). Many of the tabular and domical forms have coalesced to form an extensive reef along Lake Clifton's north-eastern coastline. It is currently unknown if there are multiple species present in the community. The thrombolites have a minimum net growth rate of approximately 0.1mm.yr^{-1} (Moore 1993, Moore and Burne 1994), which is dependent upon a persistent supply of fresh water rich in calcium, bicarbonate and carbonate. Calcium carbonate is biomediated by microbes, including cyanobacteria and other photosynthetic bacteria that depend on light for growth and survival. Associated with the thrombolites is an abundant and diverse macro-invertebrate fauna assemblage including isopods, amphipods, coleopteran, and trichopteran larvae and schrimps but also fish (Moore et al. 1984).

Microbialites, including thrombolites and stromatolites are of great scientific importance. They provide some of the oldest forms of evidence of biological evolution on Earth, and can serve as crucial stratigraphical indicators, providing information on palaeo-environment and ecological changes through recent and geological time (Moore et al. 1984). The preservation of Lake Clifton and its thrombolite community is highlighted by the fact that these structures are restricted to a few areas of limited extent, other than Western Australia, including the Bahamas, Mexico, and Bermuda. Lake Clifton is also important as a waterfowl habitat (listed jointly with lakes McLarty and Mealup and the Peel-Harvey Estuary under the "RAMSAR" Convention on wetlands as of international importance). The identification of increasing salinity levels and nutrient concentrations in the lake over the last 20 years (Barr 2003, Knott et al. 2003, Luu et al. 2004), led to the thrombolite community of Lake Clifton being assessed as endangered in 1996, and deemed critically endangered in February 2000 due to the increasing salinity and decreasing water levels being observed in lake waters (Moore et al. 2003).

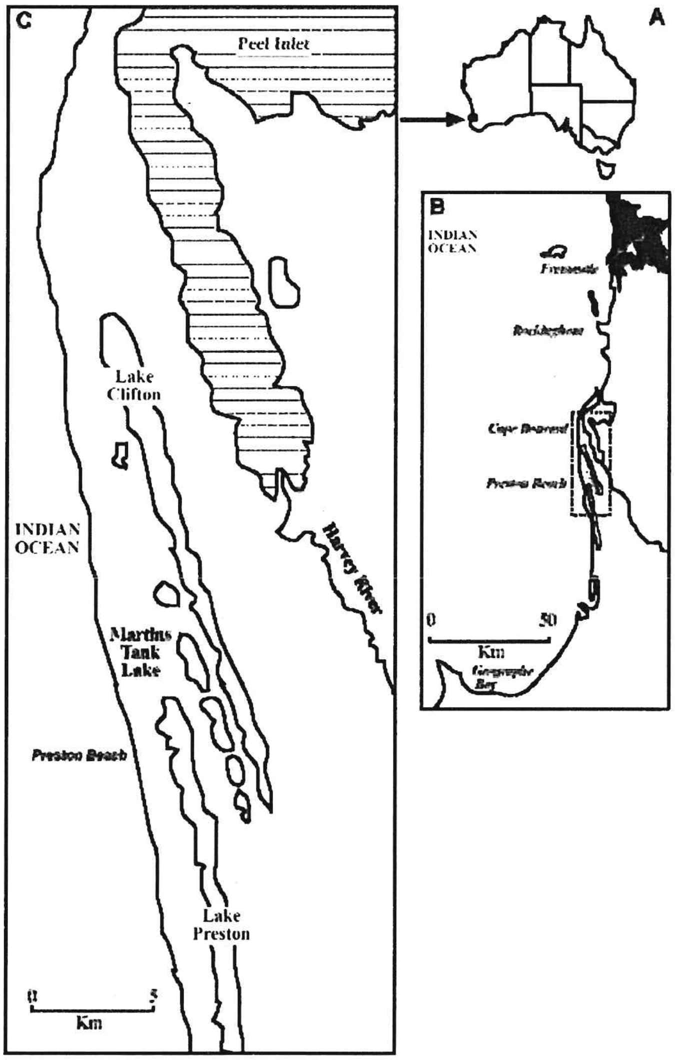

Figure 1. Location and local geomorphology of Lake Clifton (Modified from Moore and Burne 1994).

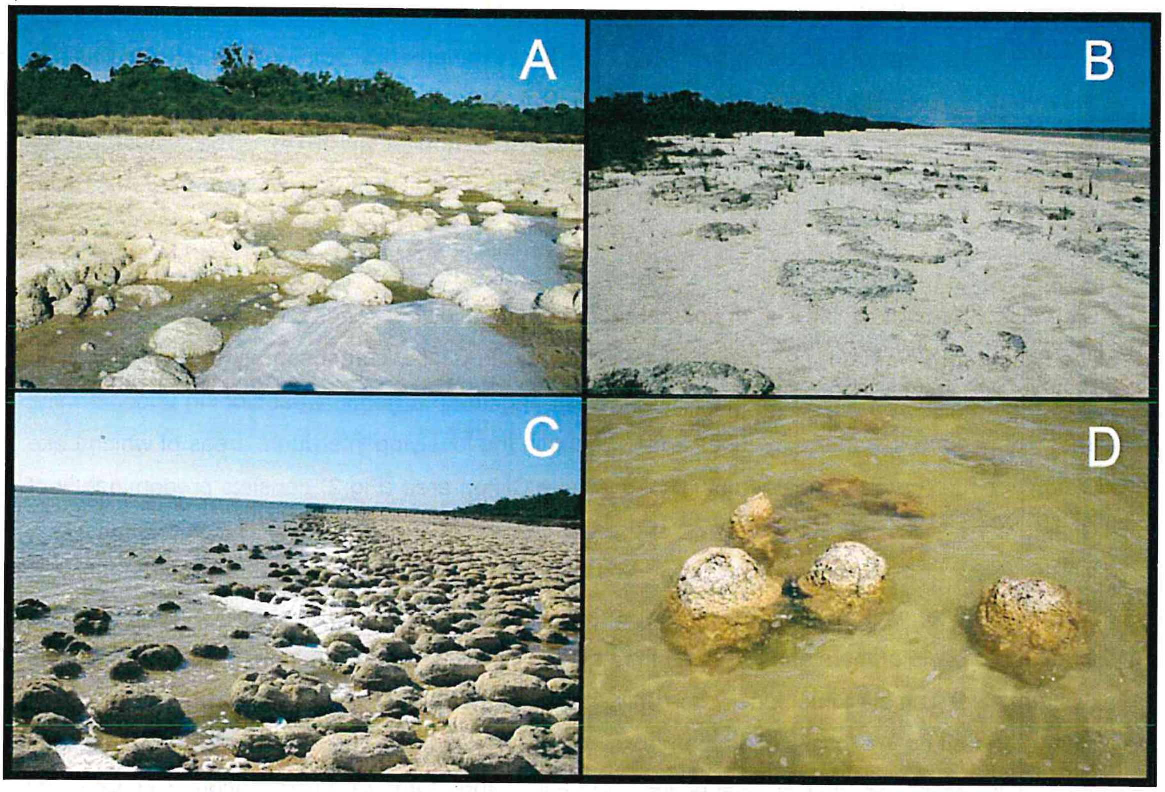

Figure 2. Various forms of thrombolites at Lake Clifton. A; Reef of tabular thrombolites that give way to isolated domical structures in the foreground. B; Tabular thrombolites with concentric rings. C; Domical, conical and tabular thrombolites south of the viewing platform. D; Three partially submerged conical thrombolites, north of the viewing platform.

2. Geology and Geomorphology.

The geology of the area in the vicinity of the Clifton/Preston (Yalgorup) lake system is described in Commander (1988). Geologically; it lies within the Perth Basin, a basin structure containing a series of strata that comprise approximately 6000m of Phanerozoic sediments. The Perth Basin is separated from the Precambrian rocks of the Yilgarn Craton by the Darling Fault to the east and extends west to the edge of the continental plate (Playford et al. 1976). The Yalgorup lake system, including Lake Clifton is located in a 10km wide coastal strip from Mandurah to Australind (Fig. 1).

Lake Clifton formed as a result of coastal progradation following sea-level changes between 3ka and 6ka years BP (Thom and Chappell 1975). The area is now comprised of series of stabilized dunes, which are parallel to the present coastline and lie on a gentle west-sloping unconformity. These dunes are separated by lakes and swamps in the low-lying interdunal areas of which Lake Clifton is one. The geological structure of the Lake Clifton area (Fig 2) consists predominantly of Quaternary aged sands (Safety Bay Sand), and calcarenite and limestone (Tamala Limestone), the thickness of these units varies between 12 and 90 metres. The sands dominate the western part of the lake, while the calcarenite/limestone predominates in the central and eastern parts, forming the basis of the stabilized dune that is apparent to the east of the lake (Spearwood Dune System). The Tamala Limestone commonly out crops along the shores of the lake and contains marine and estuarine fossils (Commander 1988). Underlying these surficial units are Cretaceous shale and siltstones of the Leederville Formation and north of Lake Clifton, the Osborne Formation.

Cores of lake sediments, reveals a sedimentary history of transition from marine through lagoonal to lacustrine conditions (Moore 1993). Present day lake sediments consist of carbonate mud, skeletal remains of ostracods and gastropods, calcified stems and oogonia of charophytes, peloids and small irregular carbonate concretions (Moore 1993), which occur down to 1m. Underneath are sediments related to estuarine and marine sequence, richer in quartz and containing bivalves such as *Katelysia*, *Mytilus* and *Brachidontes*. A distinct lateral variation in sediments due to the prevailing south west winds is evident, with the sediments on the eastern side containing more coarse sand and gravel, while on the protected western margin sediments are more fine grained (fine sand and silt).

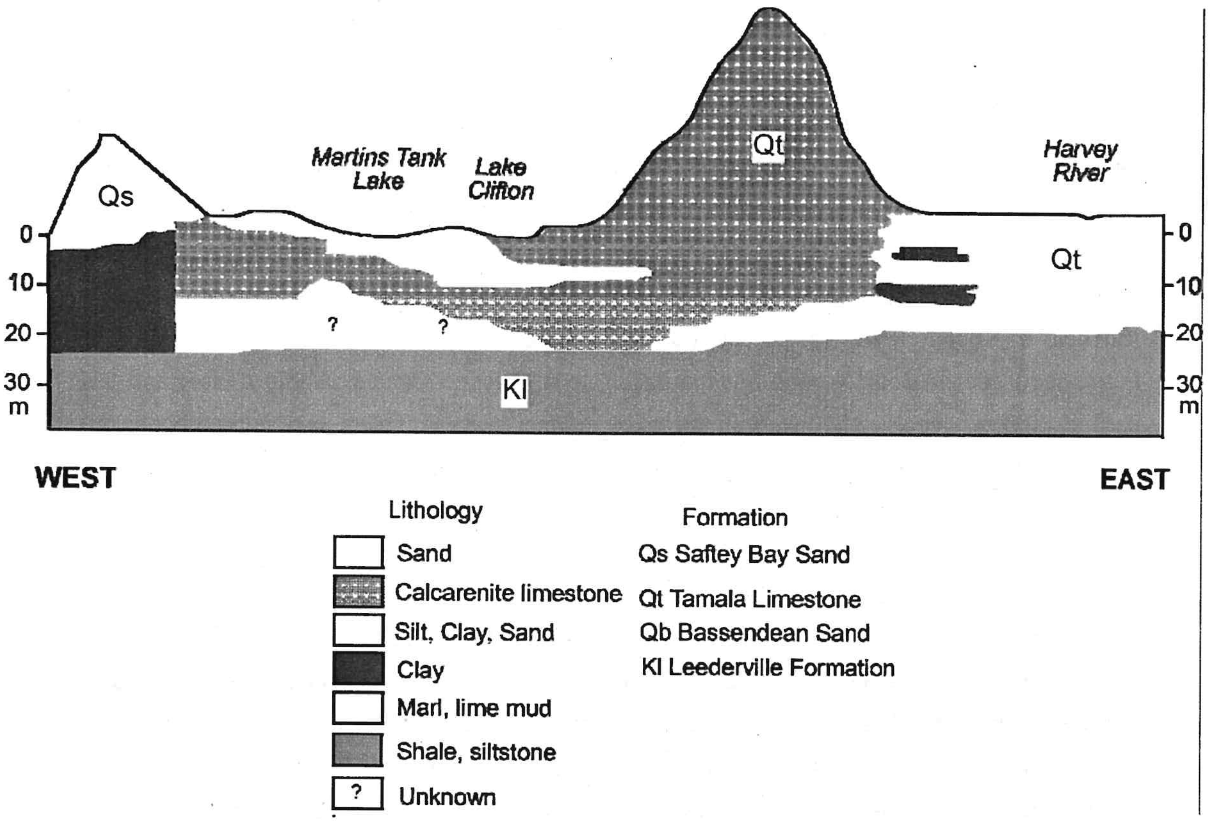

Figure 3. Geological cross section of Lake Clifton area taken (Modified from Commander 1988).

3. Age/Evolution of the Yalgorup Lakes, including Lake Clifton and thrombolite community.

The utilisation of stratigraphical examinations and radiocarbon (^{14}C) dating of Lake Hayward and Lake Clifton have allowed for an appreciation of the evolution of the Yalgorup Lake system (Coshell and Rosen 1994, Semeniuk 1995). The Yalgorup Lake system is thought to have become isolated from the marine environment during Holocene sea-level change (Semeniuk 1995). A ^{14}C age of 8000±300 yrs BP determined for sediments from Lake Hayward helped to (Coshell & Rosen 1994) temporally constrain its evolution, which was a transition from Pleistocene aeolian coastal dune sedimentation, to a Holocene limnic swamp phase, and then part of a short-lived (<1000 years) complex marine inlet. A saline lacustrine depositional environment then prevailed after 7000 yrs BP, which is identified by the abrupt disappearance of forams, certain bivalves and ostracods.

It is thought that Lake Clifton became isolated from the marine environment after Lake Hayward (Coshell and Rosen 1994). Radiocarbon dates obtained for sediments from the top of the Lake Clifton estuarine sequence, range between 4770 and 3610 yrs BP (Coshell and Rosen 1994). These sediments represent the latest part of the pre-lacustrine marine inlet phase, implying that the lake did not become isolated from the sea until at least the Holocene sea-level high stand (<5 ka years BP). The Lake Clifton thrombolite community is thought to have formed, based on the sediment ^{14}C age, between 2 ka yrs BP and present (Moore and Burne 1994).

While no direct dating has been undertaken on the Lake Clifton thrombolites, direct ^{14}C dating of microbialites has been undertaken previously (Hillaire-Marcel 1986, Casanova and Hillaire-Marcel, 1992, Last and De Deckker 1990). For instance the age of thrombolite communities in two saline volcanic maar lakes in Victoria were determined by ^{14}C dating of their carbonate fraction (Last and De Deckker 1990). These techniques could be applied to the Lake Clifton Community to provide a clear indication of their age.

4. Hydrology and hydrogeology.

Several studies have been undertaken to asses the hydrological and hydrogeological dynamics of Lake Clifton and its catchment including; isotopic (Moore and Turner 1988), geochemical (Moore et al. 1984, Moore 1987, Davies and Lane 1996), hydrogeological (Commander 1988), and hydrological/hydrogeolgoical modelling studies (Barr 2003). In the vicinity of Lake Clifton the Superficial Aquifer flow system is known as the Myalup which comprises the Yanget Mound and the Mialla Mound (Deeney 1989). Groundwater flow is away from the mound crests to local drainage features such as the coastal lakes and wetlands (Fig. 3). Hydraulic conductivity generally increases to the west (Deeney 1989).

Lake Clifton itself, is comprised of three smaller basins (northern, middle and southern), and is bounded to the south by Lake Preston and to the west (from Martins Tank) and east (from Harvey Estuary) by groundwater divides (Commander 1988). Both the northern and middle basins are permanent, while the southern basin dries out in summer. None of the three basins experience surface outflow and only occasional minor surface inputs (Davies & Lane1996) primarily through overland flow from local catchments. As a result lake water levels are dominated by groundwater input verses output and the balance between rainfall and evaporation. Fluctuations in lake level are observed seasonally due to climatic variations by approximately 1 to 2 m (Moore and Burne 1994). In general lake water levels are higher in winter due to rainfall and groundwater input and low in summer due to evaporation, when most of the thrombolites become exposed (Moore 1991, Moore and Burne 1994). Annual fluctuations in Lake Clifton are also evident, with Knott et al. (2003) observing that over a fifteen year period (1985-2000) mean yearly lake levels in Lake Clifton's northern most basin fluctuated between 4.7 and 4.1 meters.

Thus Lake Clifton displays strong seasonal trends in salinity, and was considered to be predominantly hypersaline throughout the year until the last decade (Moore et al. 1984). The aquifer in the vicinity of Lake Clifton is distinctly stratified, with the upper aquifer predominantly of low salinity water (2000mg.L^{-1}), while the lower part of the aquifer consists of dense, highly saline waters (42000mgL^{-1}). The upper aquifer is thought to be recharged by rainfall, while water of the lower aquifer is sourced from seawater intrusion and leakage from the overlying aquifer and Yalgorup Lakes.

Numerous studies have investigated the ionic characteristics of the lake systems water (Williams and Buckney 1976, Moore et al. 1984, Moore 1987, Burke and Knott 1989, Moore 2003) Moore et al. (1984) reported on cation dominance in the lake system. They identified Na>Ca>Mg>K for surface waters and subterranean aquifers in the east, Na>Mg>K>Ca for the majority of the lakes and Na>Mg>Ca>K for the lakes with lower salinity, indicating that Ca enrichment of surface water and K enrichment within the main lakes had occurred. Rosen et al. (1996) recognized similar a cation order for the lake waters, anions were also investigated providing an order of Cl>SO_4>HCO_3, that were in proportions similar to seawater. Moore (2003) indicated that the regional groundwater flowing into Lake Clifton had ionic abundances of Na>Ca>Mg>K and Cl>HCO_3>SO_4.

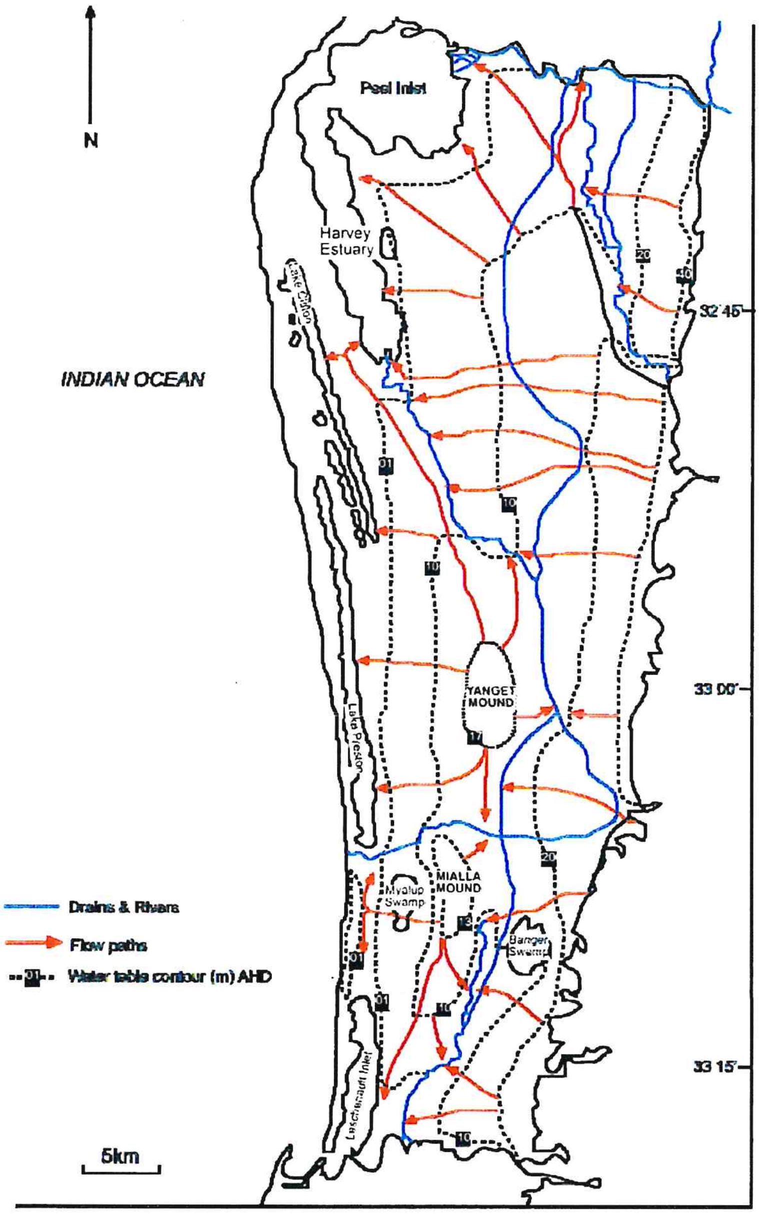

Figure 4. Regional groundwater flow systems and groundwater mounds (from Deeney, 1989).

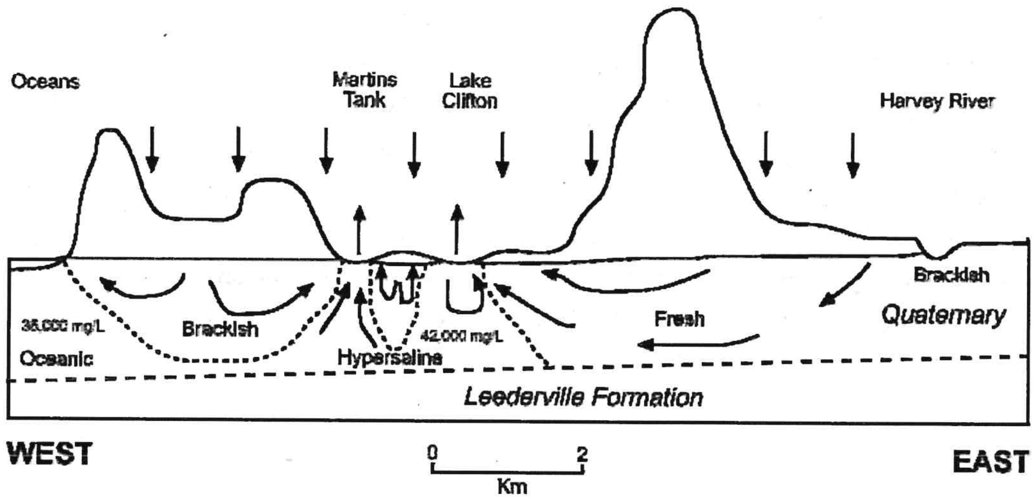

Figure 5. Hydrological cross section of Lake Clifton (Modified from Commander 1988).

As previously discussed fresh water recharge into the lake is either from direct winter rainfall or from ground water from the extensive highly permeable aquifer (115km^2). This flow is east from the Tamala Limestone (Fig. 4), under a very low hydraulic gradient, discharging into the lake along the eastern shoreline (Moore et al. 1984). In the east and southeast, the saturated thickness of the freshwater is 20 to 30m, and water table up to 10m above sea level, but elsewhere the freshwater system is underlain by the hypersaline water, causing a reduced freshwater thickness. Much of the lake area acts as a groundwater sink, with inflow's being concentrated via evaporative processes, which at the end of summer results in reflux brines discharging vertically into the underlying saline water body, (Macumber, 1991). The density of this hypersaline water body maintains the lake level close to or just below sea level.

These aforementioned interactions were confirmed by isotopic analysis of (δ^2H) ground and interstitial waters, and of (δ^{13}C) dissolved inorganic carbon (DIC) within those waters (Moore and Turner 1989). A further hydrological investigation of the water balance of Lake Clifton by Barr (2003) used the established data sets to examine three different mechanisms that may be responsible for increases in lake salinity. The mechanisms investigated were; climate change resulting in decreased rainfall and reduced freshwater inflow, the dewatering of the Dawesville Channel causing upward movement (interface up-coning) in the underlying saline groundwater, and bore water extraction within the catchment area reducing freshwater input to the lake. Unfortunately modelling of the potential for irrigation related salinity increases in groundwater were not assessed. Results from modelling these scenarios, indicated that the lake system was extremely sensitive to both rainfall and evaporation rates. Thus the lake's reduced water levels and increasing salinity were possibly a result of changing climatic conditions (Barr 2003). However, Knott et al. (2003) compared salt loads and rainfall, and noted that if rainfall was the only driving factor in determining the lakes salinity, then increased rainfall in the late 1990s and the subsequent water level rise should have returned the salinity to lower levels that were observed in the 1980s. As a result Knott et al. (2003) attributed rising salinity to an increase in the amount of brackish water inflowing to the lake system in comparison to fresh ground water, rather than rainfall. This is an important potentially threatening process as catchment activities (irrigated horticulture etc) are likely to be increasing groundwater salinity. This will obviously be increasing the salt load via groundwater inflow and when combined with declining rainfall levels could result in the observed salinity increase in Lake Clifton.

5. Threats to the Lake Clifton thrombolites.

5.1 Hydrological threats.

5.1.1 Declining water levels.

Maintenance of lake water levels has been identified as being essential to the continued living status of thrombolites in Lake Clifton. They may be able to go into some form of "hibernation" but this is currently unknown. Thrombolites rely on sufficient water to cover the growing surface of the structures, providing adequate levels of light and raw materials such as calcium and carbonate ions for their growth (Burne and Moore 1987). The fresh groundwater body to the east, which is a source of much of the lakes groundwater inflow, is under pressure from increased groundwater consumption in the area. This increased demand and decreasing groundwater levels will cause a reduction in groundwater inflow to Lake Clifton. This in conjunction with rainfall declines has/will result in the more frequent exposure of the thrombolites (and associated benthic microbial community), and thus growth restrictions on a more regular basis.

5.1.2 Increasing salinity and other changes in water ionic composition.

Increasing lake water salinity has been identified as a potential threat to the living status of the thrombolite community (Moore 1991). There has been an increase in salinity in Lake Clifton over the last 20 years. In the 1980s salinity in the northern basin was 8000-32000mg.L^{-1}, but by 2000 salinity values had increased to between 25000-49000mg.L^{-1} (Knott et al. 2003). Several processes could contribute to increasing lake water salinity; these include declining water levels, decreasing input from the fresh groundwater to the east or a salinisation of this water source. A combination of these effects could also be causing the observed salinity increases. Moore et al. (2003) highlighted the relationship between these properties identifying distinct links between lake salinity, rainfall and lake water levels (Figure 6). Increasing vertical inflow from the underlying hyper saline groundwater body into the lake water would increase salinity. The effect of increasing lake salinity on the thrombolite community is highly dependent on the flow characteristics of the lake. If there is minimal mixing between saline water and the incoming fresh water so that it still continues to inflow directly to the near vicinity of the thrombolites, then the community may not be adversely affected. However, if mixing within the lake is rapid and substantial, then there could be an impact on the thrombolites (Moore 1991). This is likely to vary with other conditions such as wind and lake level verses groundwater level. Changes to other common water constituent concentrations (i.e. carbonate, bicarbonate, Ca/Mg and acidity) could also causing issues with regard to the thrombolites. Microbialites need a continued source of carbonate and Calcium to facilitate the microbially biomediated precipitation of carbonate minerals which cause thrombolite growth similar to Lake Walyungup (Vogwill, 1996). Reductions in carbonate and calcium or increases in acidity could also be resulting in a reduced or cessation of thrombolite growth. Furthermore,

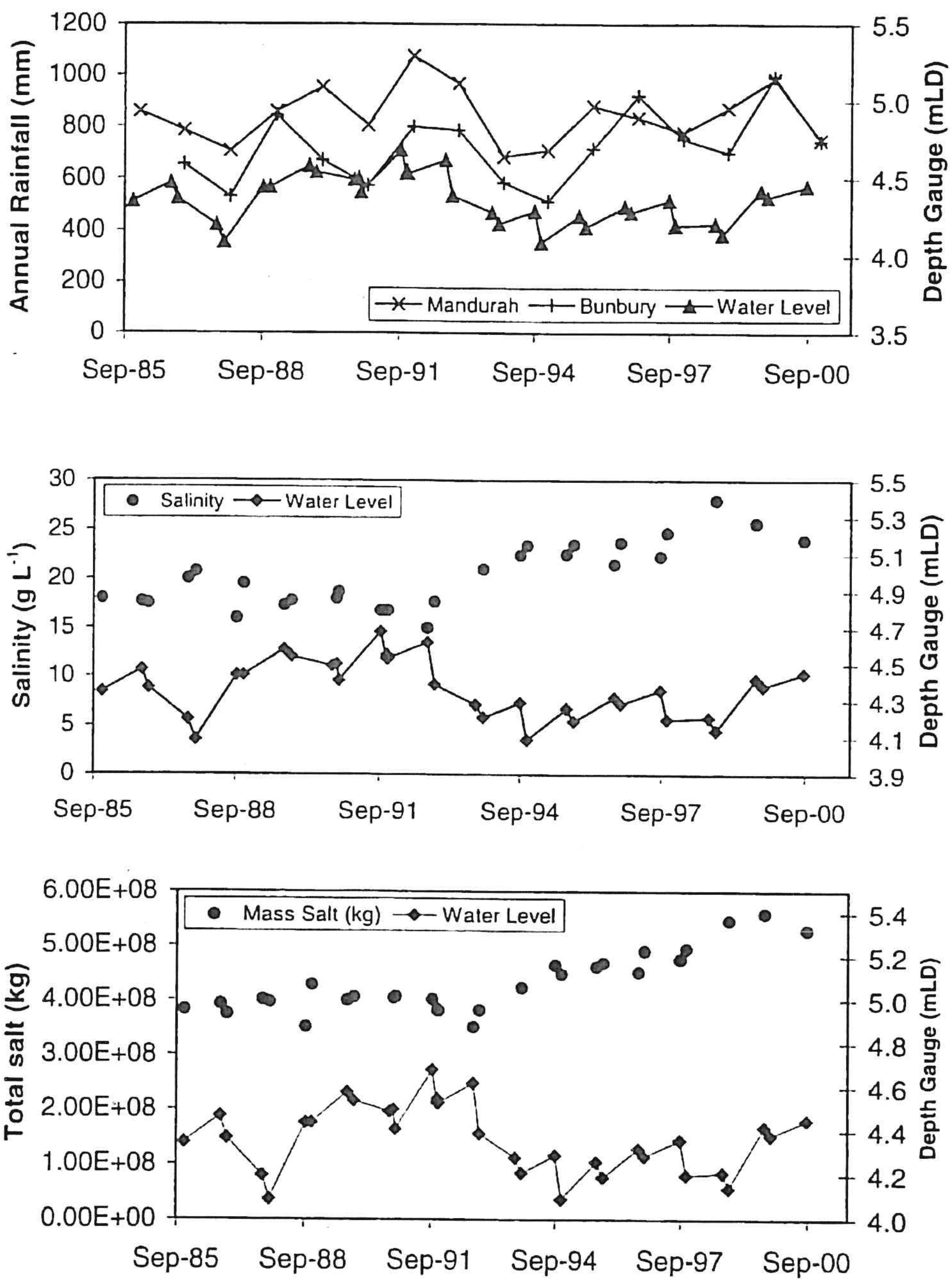

Figure 6. The relationship between lake water levels, salinity and rainfall for Lake Clifton from 1985-2000 (Moore et al. 2003).

5.1.3 Nutrient enrichment & other pollutants.

Increases in nutrient levels in Lake Clifton's surface waters and groundwaters have been observed over the last few decades. Phosphorous (P) in lake waters increased from 0.048mgL^{-1} to 0.186mg.L^{-1} between 1979 to 1988, while groundwater P went from 0.007mgL^{-1} to in excess of 0.04 in mgL^{-1}, during the early nineties (Davies and Lane 1996). The greater nutrient concentrations identified in the surface waters, compared to the groundwaters were attributed to surface runoff, resulting from areas where vegetation buffer zones had been reduced (Davies and Lane 1996). A minimum vegetated buffer zone of 200m from the high water market would be considered an effective buffer in sandy soils, to prevent nutrient enrichment in wetlands (Davis and Lane 1996). Problems associated with excessive P and N includes the creation of microalgal and planktonic blooms of other algae that can smother the thrombolites. This can result in decreased light penetration that reduces or prevents photosynthesis of the benthic microbial community inhibiting thrombolite growth. Increased phosphate concentrations have been paralleled by increase growth of the macroalga *Cladophora* in many parts of the lake (Moore 1993). Eutrophication may also cause declines in the species richness and abundance of macro-invertebrate populations which are not part of the TEC but important for the Lakes ecology.

5.2 Non-hydrological threats.

5.2.1 Human impact on the thrombolite community.

During the last 15 years visitors to Lake Clifton thrombolites have been subjected to physical disturbance, resulting from activities such as but not limited to; walking, fishing, canoeing, trampling by cattle from adjacent properties. An information bay and boardwalk have been constructed to educate people about preservation of the thrombolites and to view them without damaging the structures. This has resulted in a reduction of the impact from human activities near the boardwalk and viewing area but the benefit of these structures is restricted to a minor area of the lake. Inappropriate activities and cultures should be reduced where ever possible by restricting access to the thrombolytic structures as well as continued education of the local community and tourists.

5.2.2 Alterations to surrounding vegetation.

Clearing of native vegetation has resulted in many weed species becoming prominent within the Lake Clifton catchment area. These weed species include thistle, oats, buffalo grass, bushy starwort, annual barb grass. Problems associated with the invasion of these weeds include the creation of a more flammable environment around the lake. The increased fire regime means that there would also be an increase in sediment erosion into the lake, post fire. Nitrogen levels may also being increased due the more frequent burning (Powlson, 1987). Pesticides and herbicides used near the lake and in the catchment for weed/pest management may also impact on the thrombolites health. The reduction in native vegetation may also have an effect on the groundwater table and water balance of the catchment although this would be somewhat of an offset to rainfall reductions as reduced vegetation density or perenniality will typically increase groundwater levels and therefore inflow into the lake. If the groundwater salinity is rising however this may not be desirable.

5.2.3 Introduced fauna.

Introduction of black bream and snails to the lake may have had a significant impact on the original lake fauna and may also threaten the thrombolites. Bream and snails are thought to graze on the microbial layer that forms the thrombolites, thus may be restricting their growth.

6. Assessing and monitoring the health and status of the Lake Clifton thrombolite community.

Prior to implementing strong management actions we need to have a goal and understand how the threats and assets interact. To do this we need to understand;

1. The function and interaction of the physiochemical environment with the biological asset
2. The natural fluctuations within asset characteristics compared to anthropogenic influences
3. The ability to test hypothesis for mitigation of threats (a hydrogeological/hydrological numerical model) in terms of their cost and feasibility
4. Tolerances of the biological asset to condition decline and mortality (EWR's)

The main threat being considered in this document is that of the altered hydrology (both water volume and quality). Note that other significant threats, such as inappropriate activities/cultures and invasion of pest/weed species must be dealt with separately.

6.1 Aim.

One of the aims of this document is to propose an investigation/monitoring regime to ascertain the age, extent, health and diversity of the thrombolite community of Lake Clifton. This will aid in the assessment of hydrological threats to the thrombolites such as; altered lake salinity, increased nutrient inputs and eutrophication, lake water levels and vegetation degradation (decreased buffering). Finally, the implementation of a robust monitoring program, combined with a feasibility assessment for the mitigation of threats, will be undertaken. Well justified and robust EWR's need to be developed prior to this occurring. This will allow for the detection (via monitoring) of any increase in threat to the thrombolite community.

6.1.1 Asses the extent, health and composition of the thrombolite communities.

- Investigate and map thrombolite communities in the Yalgorup Lake System including Lake Clifton, Martins Tank Lake and Lake Walyungup (Rockingham). Asses and record the health, distribution and diversity of the thrombolite community in these environments with a focus on implications for the Lake Clifton community.
- Lakes Martins Tank and Walyungup will be incorporated into this part of the investigation as analogues to the primary investigation site (Lake Clifton) in terms of thrombolite development, health and distribution. Martins Tank Lake only contains fossil or remnant communities (Forbes, *pers comms*) while lake Walyungup has both fossil and modern communities, Vogwill, (1996).

- This is will allow us to describe current asset condition and will assist with development of EWR's.

6.1.2 Determine the age of the various thrombolite communities in the Lake system.

- Ascertain the age of the thrombolite community in Lake Clifton and possibly other lakes for comparison.
- Strategic radiocarbon (^{14}C) dating of the carbonate ($CaCO_3$) component of the microbialites.
- Thrombolites chosen for age determinations would be based on their health, distribution, community structure and proximity to established hydrological observation sites (bores).

6.1.3 Investigate the palaeo-hydrological history of Lake Clifton.

- Asses the history of the thrombolite community, including the hydrological conditions, through an investigation of fluid inclusions and isotopic analysis.
- The stringent hydrological conditions that were/are necessary for the development of the encrusting BMC responsible for thrombolite growth can be investigated and monitored via isotopic analysis of the thrombolites. $\delta^{18}O$ and $\delta^{13}C$ analysis of the thrombolites can provide insight into the conditions required for the formation of thrombolites as well as stromatolites (Casanova and Hillaire-Marcel 1992).
- Compare this palaeohydrological data to that of modern lake and groundwater to provide palaeohydrological information, preferably enough to reconstruct an approximate palaeohydrological history for the Holocene (last few thousand years) for Lake Clifton.
- This information when combined with that obtained in 6.1.2 will allow for modern changes to be put into recent geological context, i.e. is lake water quality now more saline than it has ever been before?

6.1.4 Implement multi-facet monitoring program of the thrombolite community.

- Implement a long term catchment groundwater and lake water monitoring regime for the assessment of the systems hydrological and hydro-geochemical parameters.
- Establishment of loggers that will monitor water level, EC and temperature at hourly time steps for lake water, and shallow and deep groundwater. Rainfall data will also be collected on-site using tipping bucket rain gauge in order to provide an accurate representation of precipitation at Lake Clifton.
- This data set will act a basis of which both further groundwater modelling and hydro-chemical analysis will be structured upon.

- Use geochemical (*Chlorophyll a,* NH_4-N, NO_3-N, TKN, TN, TP, TSS, pH, EC, alkalinity, acidity), isotopic (^{2}H, ^{18}O, ^{13}C) and hydro-physical (groundwater levels and lake levels) analysis for monitoring environmental dynamics of Lake Clifton.
- The monitoring program will cover the three spatially distinct basins that constitute Lake Clifton and would be undertaken preferably monthly or at least quarterly.
- Ascertain the level of the threats to the thrombolite community from increased nutrient discharge into the lake, increased salinity from groundwaters, or relative reductions in freshwater input (from declining rainfall) or any alteration to the water or salt balance of the lake.
- Investigate the impact of increased irrigation on the hydrogeological dynamics of the Lake Clifton system. This would involve the continuation of hydrological modelling (using models like MODFLOW, WSIBal, SHARP) that was developed and initiated by Barr (2003).
- Inferences can be made, from these investigations, regarding the current health of the community and the alterations in data in a modern context (i.e. salinity, pH, nutrients etc.), as well as changes in long term climate and a possible demise in community as suggested by Barr (2003).
- Ultimately the identification of the actual cause of increasing salinity within Lake Clifton. Water balance analysis combined with a catchment wide assessment of groundwater level and salinity trends will be crucial to determine the cause of increased lake salinity. Increased salinity could be caused by a number of scenarios, but management actions will depend on the cause of increased salinity.

6.1.5 Monitoring the physical condition and microbial assemblage of the thrombolites.

- The health of the thrombolites should be monitored through compositional and structural investigations (Moore 2003).
- Investigate whether macro-algae occur in the lake and look for evidence that they are a threat to thrombolite survival.
- The physical environment (mostly water quality) at each site of where these assessments are undertaken must be measured to assist in the development of EWR's.

7. Expected Outcomes

It is anticipated that the proposed investigative and monitoring strategy, when implemented, will aid in the identification of and reduction in the current threats to the thrombolite community. First, detailed insight into the microbialite communities' distribution, health, diversity and environmental conditions, both in the recent geological past and present will be achieved. Then an evaluation can be made as to whether a change in the environment or a component within the environment has affected the Lake Clifton community, and in what way. This strategy could then be expanded to other thrombolite communities identified within the Yalgorup Lakes system.

Secondly, the hydrological monitoring program will place particularly focus on water quality and lake dynamics in order to evaluate the main areas of concern highlighted as influential to the growth of microbialites in Lake Clifton (Moore 1993).

- Lake water chemistry that is favourable for carbonate deposition.
- A hydrological regime conducive to the persistence of benthic microbial community capable of forming microbialites.

Causes of changes to these key parameters can be identified with the monitoring regime and then adequate measures can be taken to reverse their influence.

A third area of concern highlighted by Moore (1993) is

- An ecological balance, which prevents the benthic microbial community from being overly disrupted by competition and grazing pressures.

This is an area which is not addressed in any detail in this document as of yet, and will the need the input of other concerned Lake Clifton parties to provide information and insight in how a strategy will be formulated to tackle this issue.

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