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History and management of Culham Inlet, a coastal salt lake in south-western Australia

E P Hodgkin

86 Adelma Road, Dalkeith, WA 6009
email: ehodgkin@cygnus.uwa.edu.au

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Abstract

When Culham Inlet was first flooded by the Holocene rise in sea level it was an estuary, but in historic times it has been a salt lake closed by a high sea bar. It is in an area of low rainfall and episodic river flow and sometimes all water is lost by evaporation to below sea level. With above average rainfall in 1989 and 1992, high water levels in the Inlet flooded farm paddocks and threatened to break the bar and a road along it from Hopetoun to the Fitzgerald River National Park. In 1993 the bar was breached to release flood water, and the Inlet was briefly an estuary. Engineering measures designed to restore road access and prevent flooding are examined for their potential to restore the Inlet to its pre-1993 condition of a productive ecosystem. Recent clearing in the catchments of Culham Inlet and nearby estuaries in the south coast low rainfall area has increased river flow to them and appears to have caused their bars to break more frequently.

Introduction

In historic times Culham Inlet has been a coastal lagoon on a semi-arid part of the south coast of Western Australia (Fig 1), separated from the sea by a high bar (Fig 2) that is only known to have broken naturally once, in 1849. The bar was broken artificially in 1920, but for over 70 years since then the Inlet has absorbed river flow without the bar breaking, until 1993. Culham Inlet was a

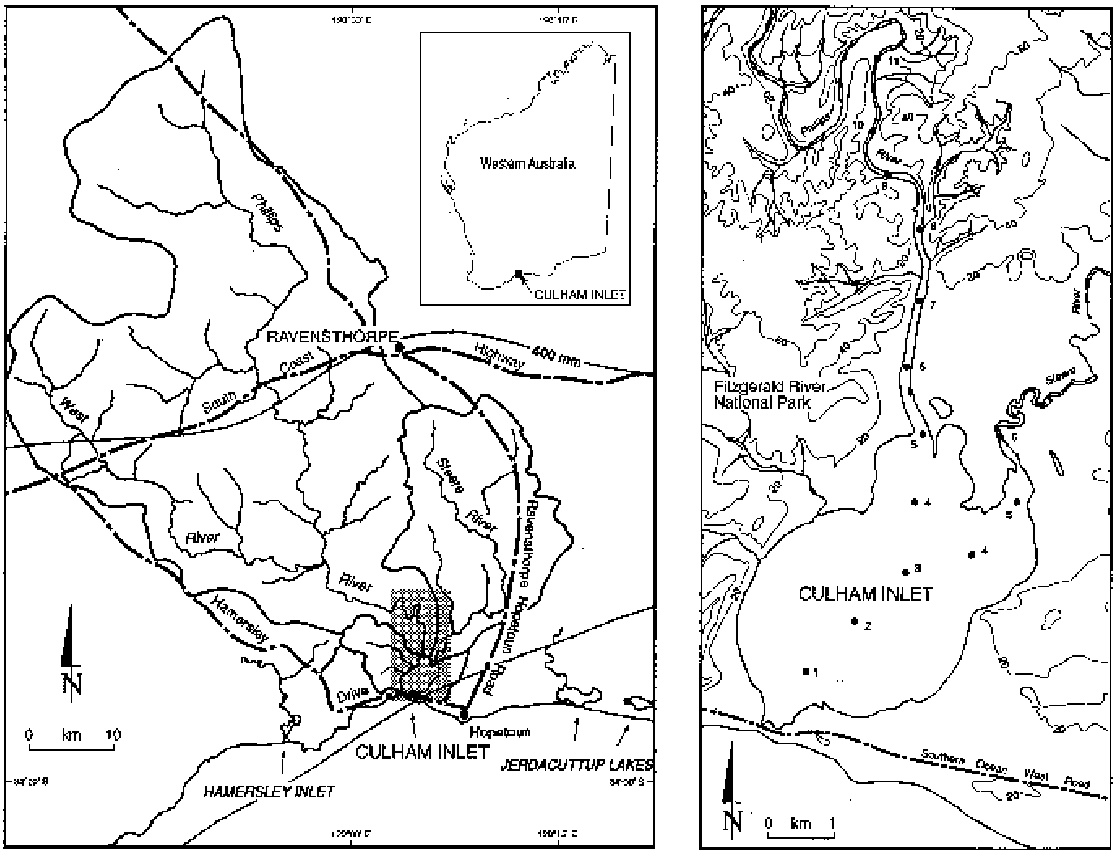

Figure 1. Culham Inlet; the catchment with 400 mm isohyet (left) and plan of the Inlet (right).

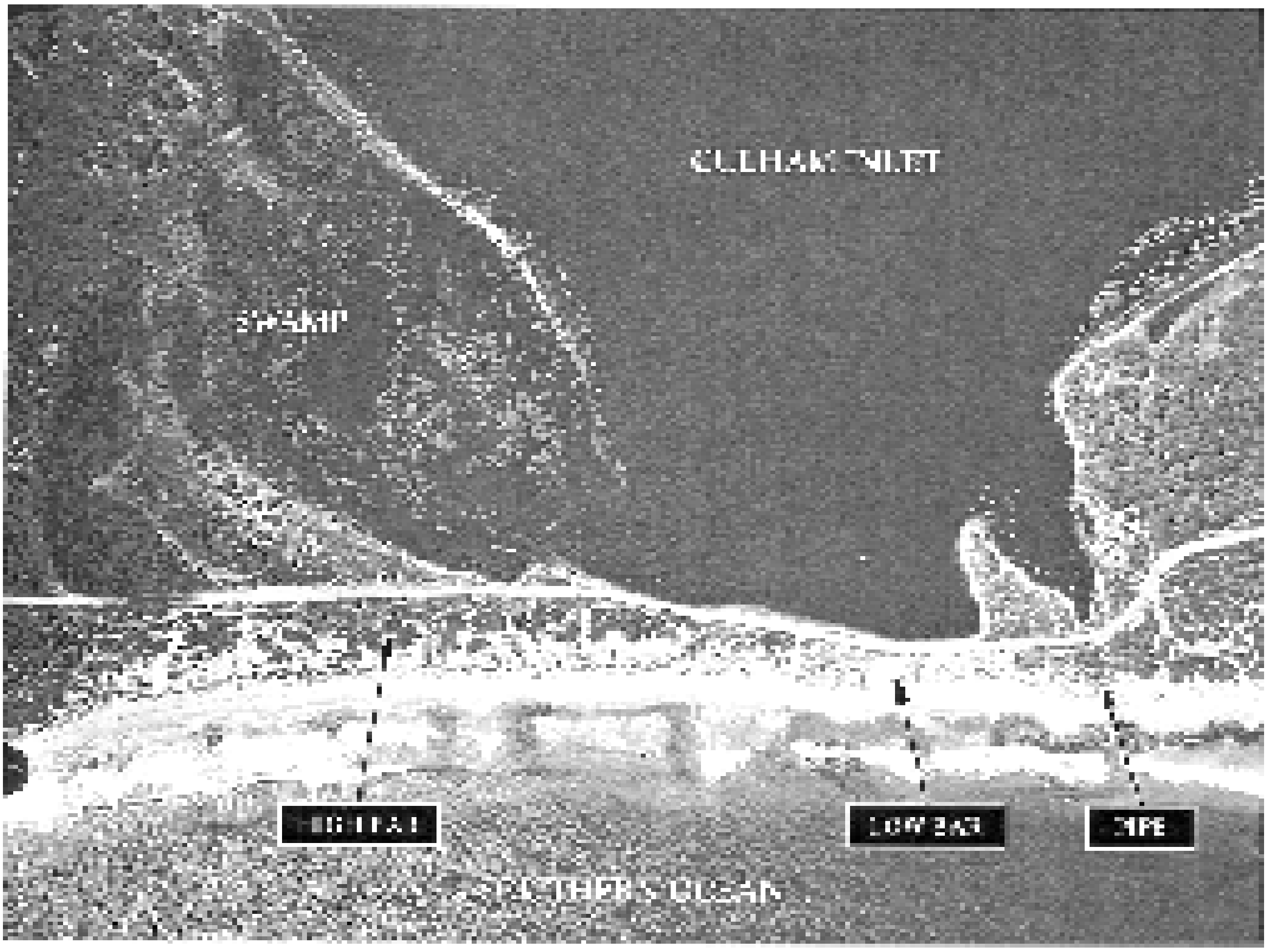

Figure 2. Culham Inlet bar / dune area, January 1990; water level at 2.5 m AHD. Scale 1:8000 Photograph from the Department of Land Administration, Perth; Copy Licence 509 / 96.

salt lake where water depth varied from 5 m to none, depending on episodic flow from two saline rivers and evaporation. Ecologically, it supported a restricted range of 'estuarine' fauna, sometimes with an abundance of a few species of fish and large numbers of waterbirds (Hodgkin & Clark 1990).

A road along the bar gave access from Hopetoun (population 206, 1991 Census) on the east to the Fitzgerald River National Park to the west, but in 1989 and 1992 floods closed the road and inundated nearby low-lying paddocks. The town's growing tourist industry suffered and there was social and economic pressure to ensure reliable road access and prevent flooding. In May 1993 the high water level in the Inlet again caused flooding and threatened to breach the bar. An attempt to release flood water without the bar breaking failed; it broke and the Inlet was effectively an estuary for a few weeks until the breach closed. Several engineering measures to rebuild the road and prevent flooding were proposed, and one was implemented in 1996-97. The unpredictability of rainfall, the limited data on river flow, and the probability that recent clearing in the catchment has considerably increased river flow to the Inlet all make it difficult to assess the environmental consequences of the various proposals to rebuild the road and the extent to which the Inlet can now revert to being a productive coastal lagoon.

The Environment

Culham Inlet is an 11 km^2 lagoon about 1 m deep below mean sea level (Fig 1B). Seven km of the Phillips River are scoured in places to 4 m below sea level, and there is a river delta at about sea level. All levels quoted here are relative to Australian Height Datum (AHD) which is 0.089 m above MSL (an accurate tidal datum was established in January 1990). The mean daily tide range is 0.67 m (MHHW to MLLW) at Hopetoun. Inlet water level varies greatly with river flow and evaporation, from +4 m to -1 m (no water). The salinity of lagoon water varies from 10 to >70 ppt. Tributary river water is seldom <5 ppt, and stagnant river pools can be hypersaline to sea water (Hodgkin & Clark 1990).

The barrier between the lagoon and the sea is a 1 km long bar, now with a dune built on it (Fig 2). The western part is a 10-15 m high dune, 100 m wide, with trees and shrubs. The eastern 400 m is 4 to 5 m high, 40-60 m wide, and sparsely vegetated.

Catchment rainfall ranges from 500 mm at the coast to 350 mm inland (Fig 1A). The only long-term (100 years) rainfall data are for Ravensthorpe and Hopetoun, both just outside the catchment. Winter rainfall is relatively reliable with 60-70% falling in the 6 months May to October (Fig 3), but the summer rainfall means are boosted by infrequent heavy falls (>100 mm). There can

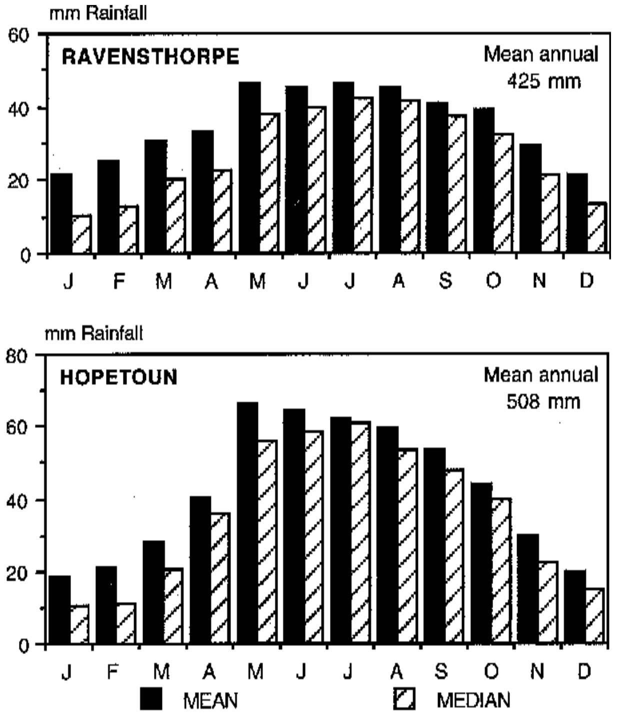

Figure 3. Mean and median monthly rainfall at Ravensthorpe and Hopetoun (1901-1993). Data from the Bureau of Meteorology, Perth.

be episodic 2-3 day falls of 50 to 100 mm in most months. A 50 mm fall, such as that of 6-8 October 1992, was estimated to recur every 7 years on average and that of 28-29 May 1993 every 2.5 years (Anon 1993a).

Mean annual pan evaporation is 1754 mm (at Esperance), but surface evaporation from the Inlet is probably only 85% of pan evaporation, as found in Peel Inlet by Black & Rosher (1980) and in reservoirs by Hoy & Stephens (1979). An estimate based on water level data in Culham Inlet and rainfall at Hopetoun (1990-1994) indicates that evaporation from the Inlet was about 1100 mm over the six summer months from November to April.

Two rivers flow to the Inlet (Fig 1), Phillips River with a catchment of 2100 km^2 and Steere River with 485 km^2. The Phillips catchment rises from sea level to about 300 m with extensive areas of sandplain and Precambrian rocks and a narrow belt of Quaternary coastal deposits (Thom *et al.* 1977; Thom & Chin 1984). Vegetation is predominantly mallee in inland areas and mallee-heath towards the coast (Beard 1972, 1973).

The rivers are not gauged, but effective annual flow probably varies from zero to >50 x 10^6 m^3, most of it as episodic events over a few days following heavy rain, as shown by the record of water level in the Inlet kept by R Cooper (Figs 4 & 5). The flow pattern is similar to that in the Pallinup River (Fig 6), the nearest river with a long gauged record.

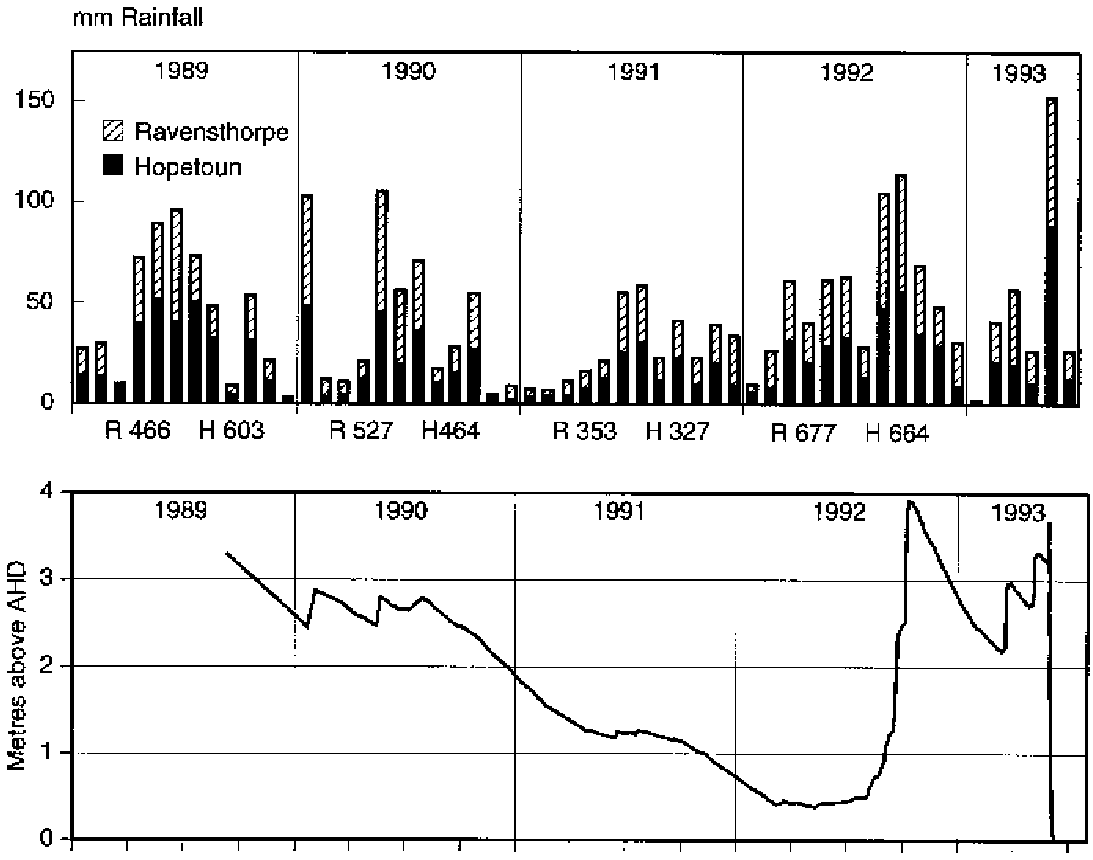

Figure 4. Top. Monthly and annual rainfall at Ravensthorpe and Hopetoun, 1989-1993 (mean annual rainfall: Ravensthorpe 424 mm, Hopetoun 506 mm). Data from the Bureau of Meteorology, Perth. **Bottom.** Water level in Culham Inlet 1989-1993. Data from R Cooper.

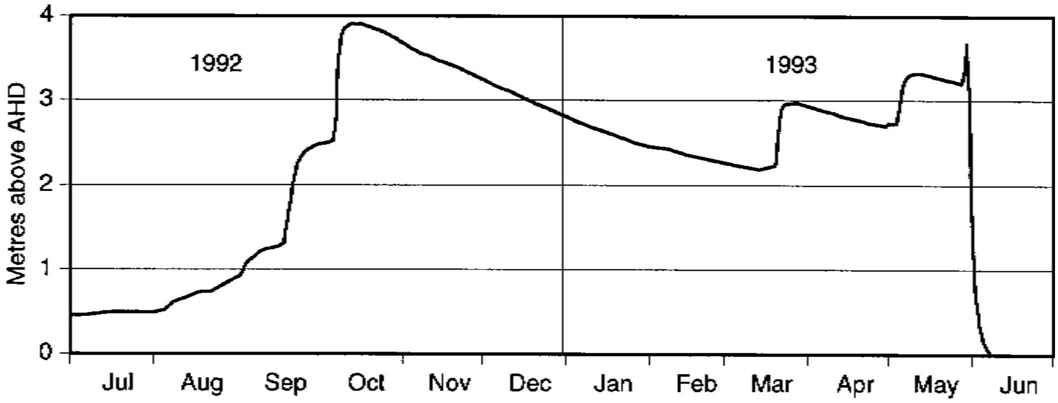

Figure 5. Water level in Culham Inlet from July 1992 to June 1993. Data from R Cooper.

The volume of river flow also varies greatly with soil moisture in the catchment. Nearly 300 mm of rain from February to July 1992 caused little flow from the dry catchment and no rise in Inlet water level (Fig 4). However that rain saturated the catchment, and in August to early October a further 300 mm of rain caused a rise in water level of 3.4 m. Only about 50 mm of rain on two days in October caused a rise of 1.5 m (about 15 x 10^6 m^3 of river flow). The capacity of the Inlet to accept such flows without the bar breaking depends on the initial water level in the Inlet, which was only 0.5 m in July 1992 but was already 3.3 m in May 1993 (Fig 5).

The area of cleared catchment (estimated from aerial photographs) increased from about 10% in 1968 to 40% by 1988. There is no record of river flow to Culham, however mean annual flow is estimated to be 3.5 x 10^6 m^3 and to have increased from 1.3 x 10^6 m^3 before clearing (data from Surface Water Branch, Water and Rivers Commission, Perth), and it may continue to increase for some time. The loss of deep-rooted vegetation, reduced moisture percolation from soil compacted by stock, and rising groundwater levels all contribute to increased runoff from the semi-arid catchment.

The Biota

Before the bar broke in 1993, Culham Inlet was periodically a highly productive ecosystem. Commercial fishers took large catches of black bream (*Acanthopagrus butcheri*) in seasons when the water level remained relatively high and salinity was <45 ppt (32 tonnes in 1990-91; 61 t in 91-92; 77 t in 92-93; Fisheries Department, CAESS, Perth) and recreational fishers also took large numbers of bream. A goby (*Pseudogobius olorum*) and two hardyheads (*Atherinosoma elongata* and *Leptatherina wallacei*) were common. There were large waterbird populations with 25 recorded species. The few euryhaline estuarine species of macro-invertebrates were abundant: the encrusting tubeworm *Ficopomatus enigmaticus* and the false mussel *Fluviolanatus subtorta* (Trapeziidae), a few polychaete worms, two amphipods and midge larvae (Hodgkin & Clark 1990). After the brief period while the Inlet was tidal, additional estuarine-marine invertebrate species (*Ceratonereis* sp, *Spisula trigonella*) were found to be common and a few opportunistic species of fish were caught, notably sea mullet *Mugil cephalus* and herring *Arripis georgianus* (Bennett & George 1994).

The Inlet has a narrow fringe of salt-tolerant flora dominated by the paperbark *Melaleuca cuticularis* backed by coastal moort (*Eucalyptus platypus* var *heterophylla*), with yate (*E. occidentalis* var *occidentalis*), *Acacia cyclops*, and *Eucalyptus tetragona* on higher ground (Bennett & George 1994). The paperbarks and coastal moorts along the eastern shore of the Inlet died following the prolonged 1989-90 flooding with saline water (about 17 ppt). The previously limited areas of samphire (*Sarcocornia quinqueflora*) have expanded greatly while the water level has been low since 1993. The aquatic *Ruppia megacarpa* was present but seldom abundant.

History of Culham Inlet

Before the post-glacial rise in sea level, Culham Inlet would have been a valley with a river flowing through it; there is about 25 m depth of sand below present sea level at the bar (Anon 1993b). By 6500 years BP the rising sea level had flooded the Inlet, at least to its present level, and it remained an open estuary until about 3500 BP as evidenced by the abundant sub-fossil fauna of estuarine-marine molluscs dated 3660 ± 185 BP (Hodgkin & Clark 1990). With only episodic river flow from the semi arid catchment the bar built to a height at which it retained river flow, perhaps at first with periodic breaks as now at ‘normally closed’ estuaries such as Hamersley Inlet (Fig 1), before becoming a ‘permanently closed’ estuary (Lenanton 1974; Hodgkin & Lenanton 1981) *i.e.* a coastal salt lake. The western bar, now with a high dune, may have closed first and the eastern low bar later.

The bar is known to have opened naturally in 1849 (Gregory 1849) and is said to have broken in the 1870s. It was opened artificially in 1918 or 1920 when floods threatened to break it during eight years of above average rainfall (1913-20), and it is reported to have remained open for about three months. The break appears to have opened a 200 m wide gap through the eastern low bar where sea water is seen seeping into the almost dry Inlet in an aerial photograph of January 1981 (Fig 7). Above average rainfall in 1955 (' 660 mm) again threatened the bar, and water is reported to have ‘trickled out’.

By September 1988, runoff from above average winter rain had raised the Inlet water level to about 3 m, with 0.8 m of water over the road along the bar at its lowest point. Again in 1989 there was above average winter

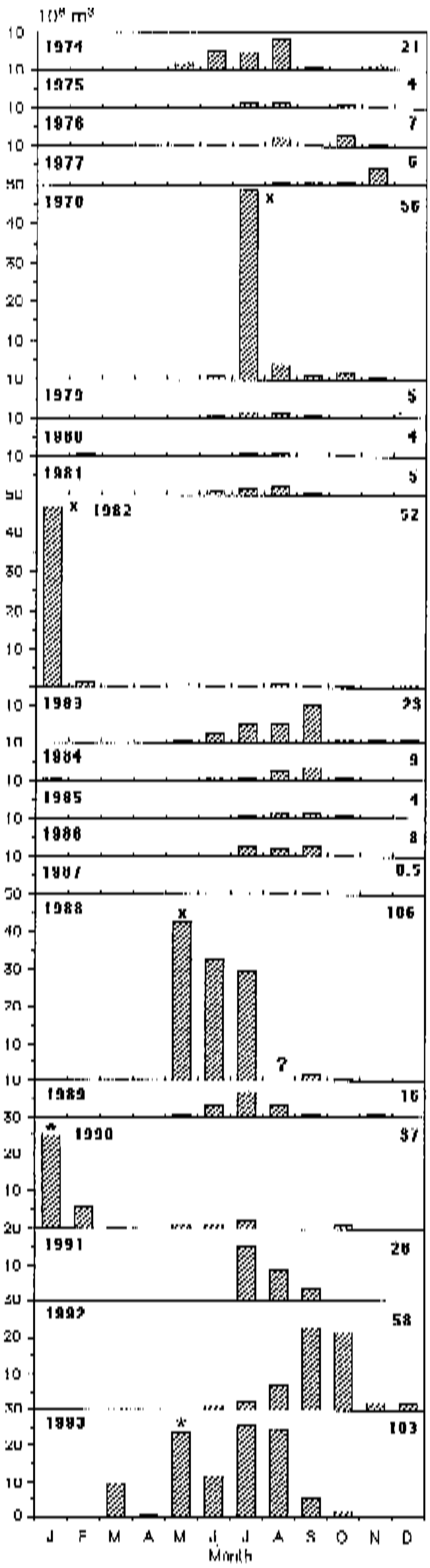

Figure 6. Monthly and annual flow (10^6 m^3) in the Pallinup River, from gauged catchment 602001 (3655 km^2). Data from the Water and Rivers Commission, Perth.

rain, the Inlet water level was about 3.3 m (Fig 4), roads and farmland were flooded, and paperbark trees and coastal moorts along the eastern shore of the Inlet died. In May 1990 a pipe of 900 mm internal diameter was installed in the eastern end of the bar, with an overflow level at 2.2 m (Anon 1993a). Rainfall was well below average in 1991, there was little river flow and Inlet water level continued to fall for the first seven months of 1992 to about 0.4 m. Early rain saturated the catchment soils and river flow from 300 mm of rain in August to October raised Inlet water level to 3.9 m (Fig 5). Water seeped through the bar / dune along its whole length and flowed strongly where the 1990 pipe discharged onto limestone shore rock.

By mid March 1993, evaporation and seepage through the bar had lowered water level to 2.2 m, which was still a dangerously high level for the beginning of winter (Fig 5). Above average rainfall in February to early May on a saturated catchment raised the water level to 3.3 m by 9 May. A cut was hastily made through the western dune to lower the water level without breaking the bar. However on 28-29 May, before the planned spillway could be completed, about 50 mm of rain brought river flow that raised the Inlet water level nearly half a metre in 48 hours, to 3.7 m. Water tore through the cut and opened a 70 m wide breach through the dune and beach to about 3 m below sea level, and then scoured a channel against the dune (Fig 8). The water level fell 3 m in 3 days but it was a week before the Inlet was tidal. Within six weeks the huge volume of sand and shells carried out to sea had rebuilt a wide beach to about 2.3 m above sea level and closed the Inlet.

Since the break, rainfall has been below average and Inlet water level has only briefly been above sea level. In February 1997 the Inlet was a salt pan, and when seen in April 1997 sea water was flowing into it through the eastern bar and through the beach at the breach in the western bar. The beach, at 2.5 m, was still effectively the bar and outside the line of the dune.

If the cut had not been made, flow from the 50 mm of rain of 28-29 May could have raised water level to 4.5 m and broken the eastern low bar (50 mm of rain in October 1992 caused a rise in water level of 1.4 m). The 300 mm of rain in August-October 1992 would also have broken the bar if the water level had not been so low (0.5 m) in July. There have been previous occasions when the bar was threatened by well above average rainfall and river flow without it breaking: e.g. from 1917-1920 (when it was broken artificially), in 1955 and from 1958-1960. But now, as noted above, river flow is probably considerably greater than on those occasions.

Management

Background to management

Following the floods of 1988-89, there was pressure from farmers and the Hopetoun community to prevent flooding and ensure road access from Hopetoun to the Fitzgerald River National Park. A proposal to cut the bar was deferred, and in 1990 the pipe was installed to lower the water level and reduce the risk of flooding. This did not have the capacity to cope with major floods and several proposals for the controlled release of flood water

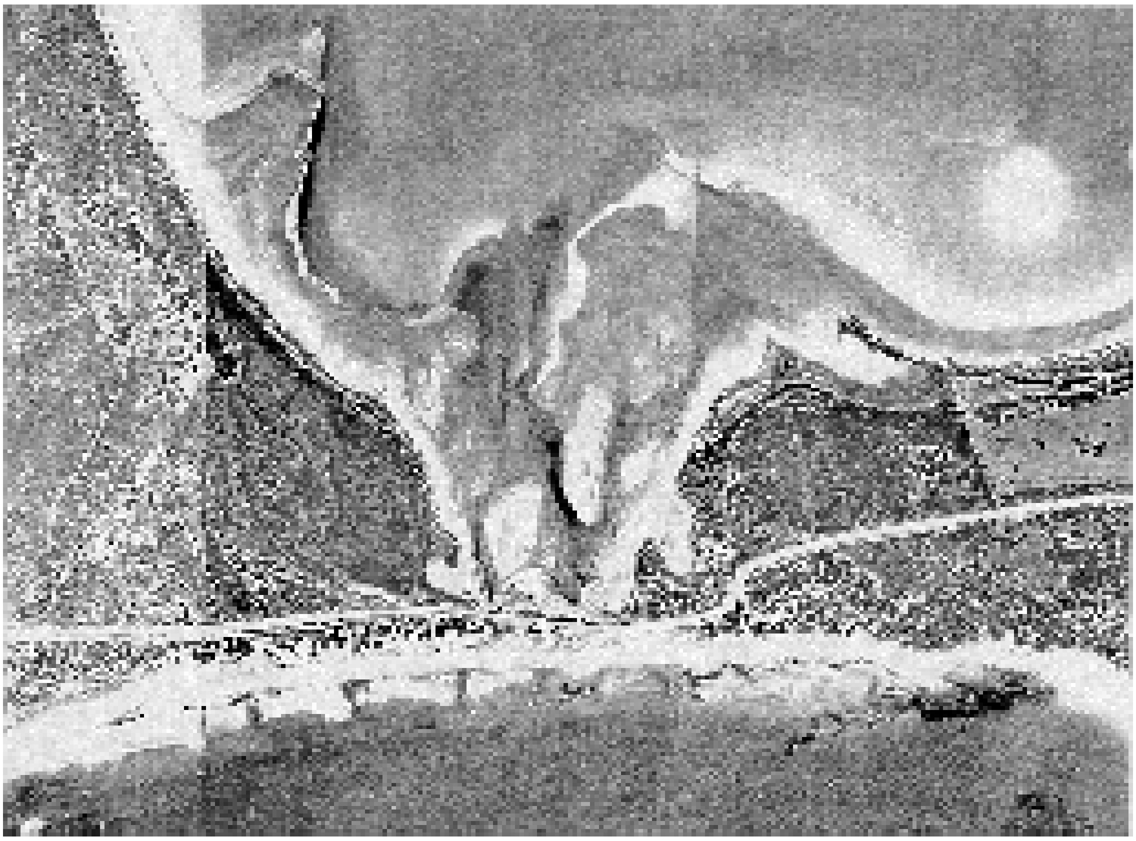

Figure 7. Culham Inlet bar/dune area, January 1981. Scale 1:15 000. Photograph from the Department of Land Administration, Perth; Copy Licence 519/97.

at the eastern low bar were examined. The high Inlet water level (3.9 m) in October 1992 again caused extensive flooding and threatened to break the bar. Continued high water levels early in 1993 made it urgent to implement the planned controlled release of Inlet water through the western high dune before winter, but this was overtaken by river flow from the storm of May 28-29 and the water broke through.

After the break, several public meetings were held at Hopetoun to discuss the future of Culham Inlet. Everyone wanted continuous road access from Hopetoun to the Park, but inevitably there were conflicts of interest and little agreement as to the level to which Inlet water should be allowed to rise. Some low-lying paddocks are subject to flooding at 2 m and farmers did not want their land flooded, commercial fishers were concerned at the potential loss of the profitable black bream fishery (Anderson & Cribb 1994) and wanted to maintain the highest possible level, as did local residents concerned to preserve the ecosystem. The compromise reached at a public meeting in July 1993 was that the Inlet should hold as much water as possible consistent with minimal flooding of paddocks and access roads, and that the road from Hopetoun to the Park should not be closed for more than about five days once in five years (Anon 1993a). A critical water level for management is 3.5 m, above which there will be unacceptable flooding.

Management options

Five engineering measures to restore road access and manage the bar were proposed and assessed. All provided for flood water to be released at the site of the 1993 break in the bar and the roadway to be rebuilt at 4 m AHD. The first four involved rebuilding the road along its former alignment adjacent to the bar. Option 5 diverted the road inland from the bar to protect the roadway from wave action and reduce scour by flood flow (Fig 8). The five management options were;

1. Build a 120 m long floodway section of roadway at 2 m (or 2.5 m) to release flood water (Anon 1993a). This allowed for the road to be closed briefly during floods, with a probability of once in five years.
2. Rebuild the road as an effectively impermeable barrier (Anon 1993b).
3. Rebuild the road with a 40 m long sacrificial section at 3.5 m to release flood water (Anon 1993b).
4. Build a 60 m long bridge over a sacrificial section of roadway at about 3.5 m to release flood water (Anon 1993b).
5. Rebuild the road in an arc about 500 m inland from the break in the dune at 4 m (Fig 8), with a 100 m long relief floodway at 3.7 m, eleven 1.8 m diameter culverts through the road embankment at an invert level of 1 m to release flood water, and one smaller culvert at -1 m to equalise water levels between the Inlet and the pool between the roadway and the bar

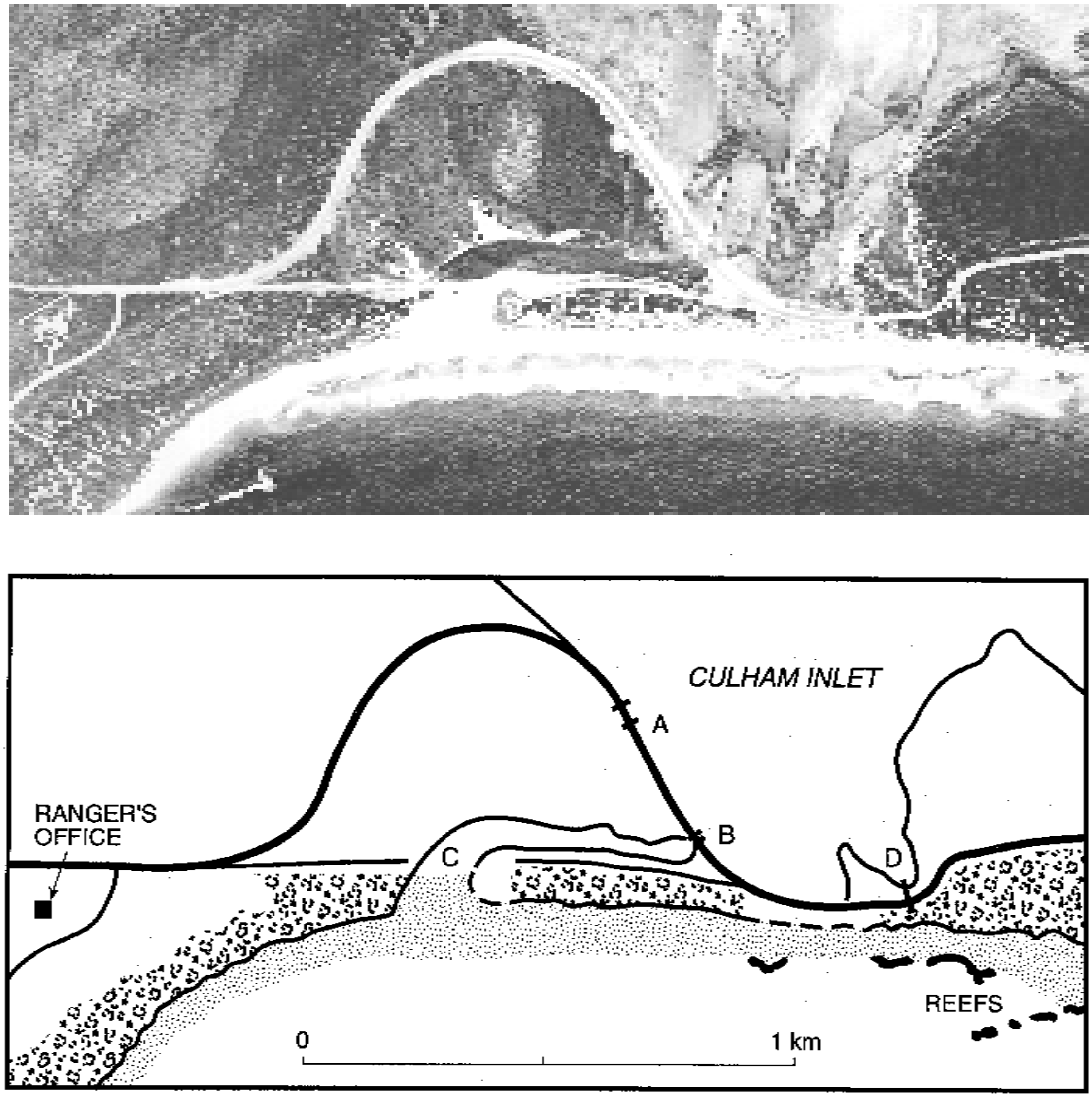

Figure 8. Top. Culham Inlet bar/dune area with the new road, January 1997. Sea water is seeping into the almost dry Inlet through the beach and through the scour channel and low level pipe. Photo from the Department of Land Administration; Copy Licence 530/98. **Bottom.** Explanatory diagram: A, culverts (11 at 1 m above AHD); B, culvert (1 at 1 m below AHD; C, the 1993 scour channel; D, site of the 1990 pipe.

(Anon 1995). If, as anticipated, the bar rebuilt to 3.5 m it would have to be broken when flood water reached that level.

Option 1 was not pursued when Option 4 was proposed. Options 2 and 3 were rejected because of the probability that floods would breach the road, perhaps once in 20 years, and access to the Park interrupted for long periods while it was being restored. Further study of Option 4 was not pursued because of the risk of "significant and uncontrolled failure [of the roadway] at less than acceptable frequencies" (Anon 1995). Option 5 has now been implemented and the road was opened officially on 15 April 1997.

Environmental considerations

The prime environmental objective for management should be to make Culham Inlet as healthy and productive a water body as possible and restore the Inlet to as near to its pre-1993 condition as is now practicable, compatible with there being minimal flooding of paddocks and access roads. To achieve this the Inlet must hold as much water as possible, for as long as possible, and with a salinity less than about 70 ppt.

There is probably little river flow to the Inlet in three out of four years, mean annual evaporation is about 1500 mm, the Inlet is only 1 m deep below AHD, the water becomes >70 ppt during long periods of low river flow, and all water can be lost by evaporation. The capacity of the Inlet to accept a river flow event depends on the area of the Inlet (11 km^2), the volume of flow (' 11 x 10^6 m^3 for every 1 m depth), the initial water level, and the height of the retaining barrier. The volume and timing of river flow depend on rainfall and the moisture content and compaction of the catchment soils. Rainfall and soil moisture are unpredictable and so too must be the volume and frequency of river flow, while the depth and salinity of water retained after flood flow will depend on the height of the barrier. On past experience, the combination of events which produced the high water levels of 1989, 1992 and 1993 might be expected to recur once in about fifty years. However, river flow may have at least doubled as the result of catchment clearing during the last 30 years, and the previous 50-year probability of a 3.5 m high bar breaking may now be a 20 to 30-year probability, and a 2.5 m bar breaking every five to seven years.

The potential for management to achieve the above environmental objective for Culham Inlet (i.e. with as much water as possible for as long as possible and the salinity less than about 70 ppt) will depend on the height of the retaining barrier and how often it breaks.

Option 1 would retain flood water to the level of the floodway (2 m or 2.5 m) with a maximum depth of 3 to 3.5 m of water. The Inlet would again be a closed salt lake, but the water would become hypersaline and all water dry up more often than in the past. Options 2, 3 and 4 have the potential to retain water to 3.5 m (Option 2 to 4 m) with the capacity to return the Inlet close to its pre-1993 condition until the water level reaches 3.5 m and the road / bar is breached. All Inlet water would then be lost down to sea level, the Inlet would be briefly an estuary as in May 1993, and would only revert to its previous condition after the barrier was rebuilt.

The Option 5 road and pipes are now in place. However four years after the bar was breached, the beach was still effectively the bar; it was at 2.5 m and still seaward of the dune line. In this situation it can be breached (either from the Inlet or by wave action) so frequently that a stable bar is unlikely to rebuild higher on the dune line naturally. When the bar breaks all water will be lost down to 1 m and leave only 2 m depth of water, water that can become hypersaline and dry up. The Option 5 proposal envisaged the bar rebuilding to 3.5 m on the dune line (Anon 1995) and at that height it would retain water to a depth of 4.5 m and Culham Inlet would have the potential to be a healthy and productive a waterbody again — while the bar held.

Discussion

Culham Inlet was an estuary until about 3500 years ago, but probably for several hundred years it has been a coastal salt lake with a high sea bar that last broke naturally in 1845. The water level varied from -1 m to 4 m AHD (0 m to 5 m deep) and salinity from 10 ppt to brine. In 1989 and 1992 river flow raised water levels in the Inlet so high that the stability of the bar was threatened, and the road along it was impassable. In May 1993 the water level was already so high that the Inlet no longer had the capacity to accept that month's river flow, and the bar broke. Following the break, the priority for management was to ensure road access to the National Park and limit paddock flooding. The road has been rebuilt; but what is the future of the Culham Inlet ecosystem? Can it be a healthy and productive environment again?

The health and productivity of Culham Inlet depend mainly on the depth and salinity of the water. Depth and salinity are dictated by rainfall and river flow, and the height of any retaining barrier and the frequency with which it breaks. It was anticipated that the bar would rebuild to 3.5 m at which height a stable bar on the dune line could be expected break with a frequency of only once in 20 to 30 years. But in May 1997 the beach was still the bar, at 2.5 m and seaward of the dune line, and it can be expected to break relatively frequently, perhaps once every five to seven years, and with such frequent breaks it is unlikely to rebuild higher naturally. When the bar breaks, the water will be lost down to 1 m, only 2 m deep, and will become hypersaline and dry up more often than in the past — considerably more frequently with a 2.5 m beach / bar than with a 3.5 m stable bar that can retain water to a depth of 4.5 m. The bar could be rebuilt to 3.5 m from the excess of sand now on the wide beach; there would be short-term flooding of farm land before the bar broke, but this would seem to be a small price to pay for Culham Inlet to have the potential to be as productive an ecosystem as is now possible.

The combination of well above average rainfall in 1992, especially in the cleared upper catchment, the saturated catchment, the high Inlet water level and the high rainfall of May 1993 may have been unusual for the time of year, but the 50 mm of rain of 28-29 May could be expected to recur once in 2.5 years. It was the large volume of river flow from that rain that broke the bar; it was beyond the available capacity of the 11 km^2 Culham Inlet to accept at that time. The nearby Jerdacuttup Lakes (Fig 1) has three times the area to absorb flow and would not have been threatened. The last time the Culham bar is known to have been threatened was in 1955 when only about 10% of the catchment was cleared, but now with about 40% cleared the river flows of 1992-93 were probably much greater. Coastal lakes and estuaries in the south coast low rainfall area are the receiving waters for river flow from catchments that have been extensively cleared since the 1960s. The bars of two 'normally closed' estuaries, Beaufort Inlet and Stokes Inlet, have broken more frequently following clearing in the catchments; and flood flow has increased sediment transport to their shallow basins (Hodgkin & Clark 1988, 1989). Landcare groups are now implementing management measures in the catchments to reverse the rising water tables and prevent salinisation, and it is to be hoped that these measures will in time reduce runoff and river flow, and soil erosion and sediment transport to the coastal lakes and estuaries.

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References

Anderson C & Cribb A 1994 Fish, floods and tourism at Culham. Western Fisheries, Autumn: 26-27.

Anon 1993a Culham Inlet outlet management works design. Unpublished Report. Kinhill Engineers, Victoria Park, Western Australia

Anon 1993b Proposed structure at Culham Inlet. Main Roads. Perth, Western Australia.

Anon 1995 Proposed structure at Culham Inlet. Main Roads. Perth, Western Australia.

Beard J S 1972 The vegetation of the Newdegate and Bremer Bay areas, Western Australia. Vegmap Publications, Sydney.

Beard J S 1973 The vegetation of the Ravensthorpe area, Western Australia. Vegmap Publications, Sydney.

Bennett K & George K 1994 Biological study of Culham Inlet. Report to the Minister for the Environment. State Government of Western Australia, Perth..

Black R E & Rosher J E 1980 The Peel Inlet and Harvey Estuary system hydrology and meteorology. Western Australian Department of Conservation and Environment, Perth. Bulletin 89.

Gregory A C 1849 Report of an examination about Doubtful Island Bay for coal, and a place to embark it, by Commander of the Colonial Schooner "Champion". Mss. Battye Library, Perth.

Hodgkin E P & Clark R 1988 Beaufort Inlet and Gordon Inlet, Estuaries of the Shire of Jerramungup. Western Australian Environmental Protection Authority, Perth. Estuarine Studies Series Number 4.

Hodgkin E P & Clark R 1989 Stokes Inlet and other Estuaries of the Shire of Esperance. Western Australian Environmental Protection Authority, Perth. Estuarine Studies Series Number 5.

Hodgkin E P & Clark R 1990 Estuaries of the Shire of Ravensthorpe. Western Australian Environmental Protection Authority, Perth. Estuarine Studies Series Number 7.

Hodgkin E P & Lenanton R C 1981. Estuaries and Coastal Lagoons in Western Australia. In: Estuaries and Nutrients (eds B J Neilson and B J Cronin). Humana Press, Clifton N J, 307-321.

Hoy R D & Stephens S K 1979 Field study of lake evaporation — analysis of data from phase 2 storages and summary of phase 1 and 2. Australian Water Resources Council Technical Paper Number 41. Australian Government Publishing Service, Canberra.

Lenanton R C J 1974 Fish and Crustacea of the Western Australian South Coast Rivers and estuaries. Fisheries Research Bulletin 13. Department of Fisheries & Fauna, Perth.

Thom R & Chin R J 1984 Bremer Bay, Western Australia. 1:250 000 Geological Series—Explanatory Notes. Geological Survey of Western Australia, Perth.

Thom R, Lipple S L & Sanders C C 1977 Ravensthorpe, Western Australia. 1:250 000 Geological Series—Explanatory Notes. Geological Survey of Western Australia, Perth.